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AVIATION FIRE CONTROL TECHNICIAN 2

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NAVY TRAINING COURSES

AVIATION FIRE CONTROL TECHNICIAN 2

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10389

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WASHINGTON: 1959

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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PREFACE

This NAVY TRAINING COURSE was written to serve as an aid for enlisted men of the U. S. Navy and the U. S. Naval Reserve who are preparing for advancement to the rate of Aviation Fire Control Technician 2. It is one of a series of NAVY TRAINING COURSES designed to give enlisted men pertinent information necessary for the proper performance of the duties of their rate.

The predominant factor in selection of content for this publication has been the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised), as it relates to AQ2. Chapters 2 through 12 present required technical information that supplements that covered in the NAVY TRAINING COURSES listed in the Reading List.

Aviation Fire Control Technician 2 has been prepared jointly by the U. S. Navy Training Publications Center, Memphis, Tennessee, and the Training Division of the Bureau of Naval Personnel. Credit is also given to the Naval Air Weapons Systems School, Jacksonville, Florida, and the Aviation Fire Control Technician School, Memphis, Tennessee, for their technical review.

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ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E–2 or 8 mos. total service.	6 mos. as E–3 or 14 mos. total service.	12 mos. as E–4.	12 mos. as E–5; total service at least 36 mos.	36 mos. as E–6.
SCHOOL	Recruit Training.		Class A for PR3, PRS3.		Class B for MN1.	Class B for AGCA, MNCA, MUCA.
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.			
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E–3 and all PO advancements.				
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.			
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.			
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E–3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.				
AUTHORIZATION	Commanding Officer		U. S. Naval Examining Center			BuPers
	TARS are advanced to fill vacancies and must be approved by district commandants or CNARESTRA.					

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48 12 NON-DRILLING	9 mos. 9 mos. 12 mos.	9 mos. 15 mos. 24 mos.	15 mos. 21 mos. 24 mos.	18 mos. 24 mos. 36 mos.	24 mos. 36 mos. 48 mos.	36 mos. 42 mos. 48 mos.
DRILLS ATTENDED IN GRADE#	48 24 12	27 16 8	27 16 13	45 27 18	54 32 20	72 42 32	108 64 38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48 12 NON-DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days 14 days	14 days 28 days 14 days	28 days 42 days 28 days	42 days 42 days 28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

READING LIST

NAVY TRAINING COURSES

Basic Electricity, NavPers 10086
Basic Electronics, *NavPers* 10087, chapters 4 and 5
Mathematics, Vol. 1, NavPers 10069B
Mathematics, Vol. 2, NavPers 10070A
Advanced Mathematics, NavPers 10071
Basic Hydraulics, NavPers 16193
Aviation Fire Control Technician 3, NavPers 10388

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Correspondence

Number	Title
CC 291	*Physics II*
CD 425	*College Algebra*
CC 435	*Plane Trigonometry*

Self-Teaching

Number	Title
MC 291	*Physics II*
MD 425	*College Algebra*
MC 435	*Plane Trigonometry*

* "Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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STUDY GUIDE

The table below indicates the chapters of this course which particularly apply to your rate. In using this table you should also refer to appendix IV and see the exact qualifications required.

Chapter	AQ	AQF	AQB
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
10	10	10	
11	11	11	
12	12		12
13	13	13	13

AVIATION FIRE CONTROL TECHNICIAN 2

CHAPTER 1

INTRODUCTION TO AQ2

The Navy, in carrying out its assigned mission, must utilize large numbers of specially trained men to maintain its air arm as a highly proficient striking force. You have now worked within the Aviation Fire Control Technician rating long enough to realize the importance of the rating to naval aviation. The personnel who man the naval combat aircraft depend on you to maintain the fire control equipment at its maximum effectiveness. In most combat operations where the aircraft's greatest defense is a good offense, the operation of the fire control equipment may, in large part, determine not only the success of the mission but also the safety of the aircraft and its crew.

How well the aircraft fire control equipment performs depends on the knowledge and skill of the Aviation Fire Control Technicians. To become an efficient Aviation Fire Control Technician, many hours of work and study will be required. This NAVY TRAINING COURSE can help you to become a good technician, but neither this nor any other course can completely train you for your job. You will learn mainly by doing.

Before studying this course, read the introductory pages if you have not already done so. Give special attention to the PREFACE and the STUDY GUIDE.

ORGANIZATION FOR MAINTENANCE

As an Aviation Fire Control Technician, you will probably be assigned to various types of maintenance activities during your naval career. The type of activity may be any one of several types of squadrons or supporting facilities. Also, it might be well to keep in mind that any one of these activities may be located ashore or afloat. However, the class of maintenance that you may be called upon to carry out will not vary from the three established classes—line, hangar, and shop.

Regardless of the activity or its location, it will be beneficial for the technician to have a knowledge of HIS POSITION in the organizational structure of that activity. The technician should know to whom he is directly responsible and who is responsible to him. Furthermore, he should be

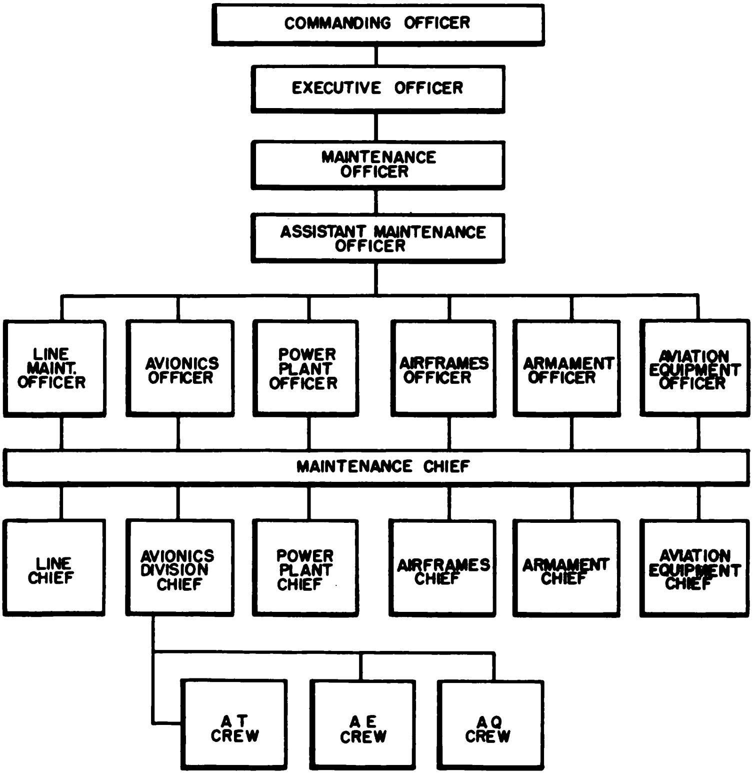


Figure 1-1.—Organization chart of a typical maintenance activity or squadron.

certain of his primary assignment or task and act accordingly.

In all probability the Aviation Fire Control Technician 2 will be a member of a crew working primarily out of an avionics shop. He will be directly responsible to the crew leader or the chief in charge of the fire control section of the shop. However, the Bureau of Aeronautics has established a uniform organization format to be followed as closely as possible by all maintenance activities. It is possible that circumstances may necessitate deviation from the uniform organization, but the basic framework will be retained. Figure 1–1 illustrates the organization of a typical activity or operating squadron.

Shore facilities for the maintenance of aviation fire control equipment consist of Overhaul and Repair (O&R) departments at major naval air stations, Fleet Aircraft Service Squadrons (FASRon's), and Self-Supported Squadrons. Facilities afloat consist of aviation fire control shops under the control of the air department of aircraft carriers. At the present time these shops are manned by squadron personnel, and each squadron is responsible for their own maintenance.

DUTIES AND RESPONSIBILITIES OF THE AQ2

Military

Since you are already a petty officer, you should realize that the rate of Aviation Fire Control Technician, Second Class, requires that you exercise leadership. Not only are you required to have technical knowledge of the equipment, but you are also required to supervise lower rated personnel. These abilities increase in importance as you advance through the various rates as a petty officer. As you advance in rating, your worth to the Navy will be judged on the basis of the amount of efficient work you obtain from your subordinates. Since you are a military leader as well as a technical supervisor, you must meet the military requirements commensurate with your rate. Be sure that you equip yourself with both the military and professional qualifications of your rate as an Aviation Fire Control Technician, Second Class.

A petty officer's working relationship with others is of great importance to the success of his work and the mission of his activity. In your day-to-day working relationships, you will be required to cooperate with others. This is not only true within your own division but with men in other divisions. In performing technical skills, the ability to "get along" is at times just as necessary as proficiency. This ability is within itself a definite skill and can be developed the same as a technical skill. You must be able to understand another man's job and his problems, and recognize his abilities. You must also be able to teach and lead men and in most cases inspire the men with whom you work and for whom you are largely responsible.

To help you develop these skills, detailed information is given in *Basic Military Requirements*, NavPers 10054, and *Military Requirements for Petty Officers 3 & 2*, NavPers 10056. You should be familiar with the entire contents of both training courses prior to taking the examination for advancement in rating.

Professional

The AQ rating is composed of a group of rates which require basically the same aptitudes, training, experience, skills, and abilities. The degree of complexity that the AQ must face in performing his work is determined by his rate. Appendix IV of this training course is a detailed listing, by rate, of the practical factors and examination subjects required of AQ's. You, as an AQ2, will probably spend most of your time performing jobs that deal with the installation, removal, servicing, troubleshooting, and maintenance of aircraft fire control equipment. A partial listing of the jobs you will be required to perform are as follows:

1. Operate the following test equipment:
   a. Signal generator.
   b. Frequency meter.
   c. Sweep generator.

2. Perform tests, adjustments, and repairs necessary for proper operation of:
  - a. Power supplies.
  - b. Electromechanical, electromagnetic, and mechanical computers.
  - c. Servomechanisms and synchro circuits.
  - d. Aviation fire control electronic circuits.

3. Effect field changes in accordance with instructions on aviation fire control systems and bomb director systems.

4. Interpret schematic diagrams and wiring diagrams found in technical maintenance publications.

ADVANCEMENT OPPORTUNITIES

An Aviation Fire Control Technician's rate indicates his pay grade and also the level of his aptitude, experience, knowledge, skill, and responsibility. Advancement in the rating is dependent on meeting certain military and professional requirements which are listed in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). The professional qualifications for the AQ rating are given in appendix IV of this training course. The qualifications as given for the AQ2 have been used in determining the contents of this course.

Reserve personnel striking for second class and above will continue in their Emergency Service Rating. Regular Navy personnel striking for second class and above will continue in the General Service Rating. This means that the AQF or AQB, Regular Navy third class, will advance to AQ2 General Service Rating. This also means that the "Quals" for the Regular Navy man include both the AQB and AQF qualifications combined for second class and above. Therefore, all chapters of this course pertain to the Regular Navy man striking for second class. Reserve personnel should refer to the study guide in the front of this course for a listing of the chapters that should be studied in preparing for a particular advancement.

Practical factors.—Practical factors are those skilled operations that you must be able to perform prior to your advancement. These are set forth in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised), and also included in appendix IV of this training course. They include the minimum skills and abilities that you should possess in order to advance. You can become skillful in performing these operations by closely observing the work of experienced AQ's and by practice. Make it your business to actually perform each of the practical factors required of you for advancement.

Closely associated with the practical factor section of the qualifications is the *Record of Practical Factors*, NavPers 760 (AQ). This form includes a list of both the military and professional practical factors for which you are responsible. Instructions for completing this form are provided at the top of the first page.

Each man studying for advancement in rating should have a copy of this form for his personal record and guidance. A copy of this form is held by the division officer or other appropriate supervisor for each man in pay grade E–3 through E–6. Upon transfer of an enlisted man, the supervisor's copy of the form is signed, inserted in the correspondence side of the service record, and forwarded.

The appropriate items on NavPers Form 760 (AQ) must be completed before you are eligible to take the examination for advancement in rating. It is your responsibility to insure that the supervisor's copy of Form 760 (AQ) is appropriately completed.

EXAMINATION SUBJECTS.—These qualifications include the minimum knowledges necessary for performance of the practical factors and must be fulfilled by passing a written examination. A complete list of these qualifications for the AQ rating are included in appendix IV of this course and in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). As stated previously, these qualifications are the basis for the contents of this course.

SCOPE AND PURPOSE OF THIS TRAINING COURSE

The purpose of this training course is to aid the third class petty officer in his advancement to second class petty officer. It may also serve as a reference source for other AQ rates.

This course presents information that is peculiar to aviation fire control equipment. In order for you to make satisfactory progress, you must possess a sound background. That is why it is a good idea to stop at this point and take inventory of the things you DO NOT KNOW.

You will find that appendix IV will be of great use in taking stock of the gaps in your technical knowledge. This appendix lists the practical factors and examination subjects contained in NavPers 18068 (Revised). You should be thoroughly familiar with these before preparing for advancement. It will also prove helpful when it is time to take your examination. The lists will serve as a guide and help you check subjects on which you need further instruction.

In your preparation for advancement in rating, you should keep in mind that the information contained in the AQ2 training course is based on the basic information discussed in *Basic Electricity*, NavPers 10086, and also information in AQ3, NavPers 10388.

The AQ2 course will not duplicate the information contained in the basic courses but will show the application of these basic theories in aviation fire control equipment. All basic courses listed in the reading list should be available for ready reference and study.

There are many other sources of information that will prove helpful to you and many of these are mentioned as reference material throughout this course.

NAVY TRAINING COURSES may be obtained from your I&E office (education) or division officer. Other publications referenced in this course may be found in your shop or technical library.

Remember, one of the most important tools of learning is the ability to know HOW and WHERE to find information.

A bibliography entitled *Training Publications for Advancement in Rating*, NavPers 10052, is issued in revised form annually by the Bureau of Naval Personnel. This booklet lists Navy Training Courses and other publications required or recommended for study for the advancement in each of the rates and ratings. This booklet is also applicable to Naval Reservists on inactive duty. It is a bibliography of reference sources from which examination questions for your advancement will be taken. Training courses marked by an asterisk must be completed for specific rate levels before you are eligible to take the advancement examination. It must be realized that, as indicated in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068, all higher pay grades listed in this booklet may be held responsible for the materials in the publications listed for the lower rates of that particular rating.

Since, in many instances, only pertinent sections of publications are listed in *Training Publications for Advancement in Rating*, the most intelligent use will be made of this booklet by concurrent reference to the *Manual of Qualification for Advancement in Rating* for the rating concerned. Also, make certain that the latest Change to the Manual is being used.

Another publication which is very helpful to the technician desiring to advance to a higher rate and become more skilled in his present rate is the *List of Training Manuals and Correspondence Courses*, NavPers 10061 (latest edition). This publication is published and distributed at regular intervals to all ships and stations. Thus, every individual may be kept informed of all the latest training courses and correspondence courses available. The publication contains lists of manuals and courses for both officer end enlisted personnel. It also contains the information necessary for obtaining all of the courses. These courses are supplied and administered by the Navy and are completely separate from the USAFI program; therefore, there is no expense to the individual.

SUGGESTIONS FOR STUDYING

This course deals with aviation fire control equipment as it pertains to the AQ2. You will be faced with technical terms and discussions that will be strange and difficult when you start to study this course.

First, glance through the entire book in order to become familiar with the general contents of the course, such as chapter and paragraph headings and the illustrations.

Then read each chapter very carefully, studying the text and the illustrations. When you have finished this reading, answer as many of the end-of-chapter questions as possible. Reread, paying particular attention to the difficult portions and discussions covering the questions you might have missed the first time. Again, answer the questions. By this time you should have a thorough understanding of the course.

For additional information concerning suggestions for studying this course, refer to chapter 1 of *Aviation Fire Control Technician 3*, NavPers 10388. Also, chapter 21 of *Basic Military Requirements*, NavPers 10054, may be of interest to you since it contains information concerning advancement and training.

From time to time throughout this course you will be referred to other Navy Training Courses for technical information. You must understand the referenced information before you can expect to make satisfactory progress in the AQ2 training course. It is also recommended that you review the basic publication *Basic Electricity*, NavPers 10086.

QUIZ

1. Your responsibility as an AQ2 demands that you
   a. maintain fire control equipment at its maximum effectiveness
   b. know and perform the duties of your rate to the best of your abilities
   c. conduct yourself in such a manner as to reflect credit on the Navy, your rate, and yourself
   d. do all the above

2. As an AQ, you will be working with the AT and AE crews and will be directly responsible to the
   a. AT Chief
   b. Avionics Chief
   c. AQ Chief
   d. AE Chief

3. The ________ has control of the Aviation Fire Control Shop aboard a carrier.
   a. Air Department
   b. Avionics Officer
   c. Maintenance Chief
   d. Avionics Chief

4. Your first responsibility as a second class petty officer will be to
   a. get along with your subordinates
   b. understand the problems of your men
   c. teach and lead men
   d. fulfill the mission of your task

5. The tools of your trade are
   a. maintenance and test equipment
   b. handtools
   c. publications and manuals
   d. all of the above

6. As an AQ2, you should
   a. familiarize yourself with all manuals and publications concerning the equipment on which you are presently working
   b. have a thorough understanding of the basic concepts of all equipment for which your rate is responsible
   c. have a thorough knowledge of all bomb director systems presently in use
   d. have a thorough knowledge of all fire control systems presently in use

7. Upon transfer from one activity to another, you should
    a. inform your division chief you have your practical factors completed
    b. insure that NavPers 760 (AQ) is in your service record and up to date prior to transfer
    c. have sufficient funds to defray expenses
    d. request a letter stating your qualifications for advancement

8. If while studying this course you encounter explanations which you do not understand, you should
    a. request a school assignment
    b. ignore them
    c. ask your division officer for an explanation
    d. study the explanations and any pertinent references listed more carefully

9. When consulting the publication *Training Publications for Advancement in Rating,* NavPers 10052
    a. study only that reference material which applies to your rate
    b. disregard those publications listed for AQ3
    c. be sure it is the current issue, as recommended study material may change
    d. disregard all material listed for additional study

10. When answering end of chapter questions
    a. do not let the difficult questions bother you, as your shipmates will gladly give you assistance
    b. reread and pay particular attention to difficult portions
    c. answer as many questions as possible before studying the chapter to reduce study time
    d. memorize the questions as they may appear on the rating exam

CHAPTER 2

ELECTRONIC TEST EQUIPMENT

As an Aviation Fire Control Technician 2, you must be able to test, adjust, and repair equipments containing electronic circuits such as power supplies, voltage and power amplifiers, phase detectors, amplitude modulators, and servomechanisms. You must be capable of testing these circuits for continuity, shorts, and grounds; measuring electrical quantities such as voltage, current, power, frequency, and phase angles. Therefore, it should behoove you to exert maximum effort in the study of electronic test equipment. This chapter will discuss the application of electronic test equipment as well as some of the equipment.

Many of the general-purpose electronic test instruments have been previously described in detail in the Navy Training Courses *Basic Electricity*, NavPers 10086, *Basic Electronics*, NavPers 10087, and *Aviation Fire Control Technician 3*, NavPers 10388. However, this chapter will provide information on the selection of proper test instruments and their operating limitations.

USE OF METERS

Aviation fire control maintenance shops are equipped with various types of meters for the measurement of electrical quantities. They range in complexity from a simple plug-in ammeter to an electronic volt-ohm ammeter. The technician must exercise judgment in the selection of the proper test instrument to insure the desired results. He must not only base his selection on the type of meter and its operating ranges, but must also consider the effect the meter will have on the circuit being tested.

In this section our primary concern will be a discussion of the more prominent sources of error that must be considered in the choice of test instruments. However, we shall first review a few basic facts on the use of meters. They are:

1. The accuracy of an electrical measurement can be no greater than the design accuracy of the meter itself.
2. D-c meters should be used for measuring d-c voltages and currents.
3. A-c meters should be used for measuring a-c voltages and currents.
4. The meter selected should have adequate ranges to cover the measurements desired.
5. The range selected for the final reading should give a midscale reading if possible.

There are several common sources of error that must be considered in the use of any meter. One source is the use of a meter within a strong magnetic field. The magnetic properties of the meter movement will be influenced by this field and consequently the meter reading will be inaccurate. If the batteries of a multimeter are metal cased, the metal casing of the batteries might become permanently magnetized and continue to influence the meter movement even after being removed from the magnetic field. In this case, correction can be made only by replacing the batteries.

Another source of error in meters is the change in resistance of multiplier and shunt resistors, coils, and other electrical components due to an extreme temperature change. This error is very prominent in a-c voltmeters utilizing copper oxide metallic rectifiers. The copper oxide film changes resistance as the temperature changes. These instruments tend to read higher than normal as the temperature increases, requiring the use of a temperature correction chart for accurate measurements. The expansion and contraction of mechanical parts of the meter movement with a change in temperature also causes inaccuracies in meter readings. Although it is not commonly done, some multimeters, such as the TS–352/U, are temperature compensated to enable them to operate accurately at extreme temperatures.

Another source of error common to meters is the result of moisture which produces fungus and corrosion, resulting in the change of resistive, inductive, and capacitive values of the precision components of the meter. An error in voltage or current readings is sometimes caused by surges or variations in voltage in the circuit being tested. This is not the fault of the meter but is an error that must be considered in erratic circuits.

Ammeter

The ammeter used for routine alinement and adjustment of an aviation fire control equipment is normally specified by the *Handbook of Service Instructions* for the equipment. Since the ammeter has to be connected in series with the current path, circuits requiring frequent current readings or adjustments normally provide current jacks for use with a plug-in meter. Some equipments have a meter installed as part of the equipment, with a meter switch to provide the necessary ranges.

Ohmmeter

The Navy does not normally supply its maintenance facilities with an instrument consisting solely of an ohmmeter. The ohmmeter is incorporated with the voltmeter to form a multimeter. Therefore, the choice of ohmmeter should be determined by the resistance ranges available in the various multimeters. Small multimeters, such as the TS–297/U, have a high range of $R \times 100$; while larger multimeters, such as the TS–352/U, have a high range of $R \times 10{,}000$. The VTVM TS–505A/U has a high range of $R \times 1{,}000{,}000$ and should be used where high values of resistance must be measured. When it is necessary to have high accuracy in the measurement of resistance, it is necessary to use a balanced bridge-type instrument which will be discussed later in this chapter.

D-C Voltmeters

The selection of a d-c voltmeter is normally based on the sensitivity of the meter movement and its effect on the circuit being tested. Meter sensitivity was discussed in *Basic Electricity*, NavPers 10086, and *Basic Electronics*, NavPers 10087, and will not be discussed in this chapter.

A multimeter having low sensitivity may be used for quick, rough readings where approximations are adequate. When a high degree of accuracy is desired, a meter having high sensitivity is required. Such a meter has wide application in the maintenance of medium- and high-impedance electronic circuits found in aviation fire control equipments.

A vacuum tube voltmeter, because of its high input impedance, is the ideal instrument for measuring low voltage in oscillators, automatic gain control, automatic frequency control, and other electronic circuits sensitive to loading. When measuring voltages in excess of 500 volts, a multimeter having a sensitivity of 20,000 ohms per volt will have an input impedance equal to or greater than most vacuum tube voltmeters. This can be proven by comparing input impedances of the two types of meters. The input impedance of most vacuum tube voltmeters is between 3 and 10 megohms. A 20,000-ohm-per-volt meter, when reading a voltage of 500 volts, would have an input impedance of 500 × 20,000 or 10 megohms. Therefore, on the 500-volt scale a multimeter of this sensitivity would have an input impedance at least equal to the vacuum tube voltmeter. For voltage readings over 500 volts, a 20,000-ohms-per-volt multimeter offers an input impedance higher than the vacuum tube voltmeter.

Any multirange voltmeter, though its sensitivity may not exceed 1,000 ohms per volt, can be used in an emergency to obtain reliable readings in a d-c circuit. If the impedance of the circuit being tested is not known, a comparison of two voltage readings, one on the lowest usable range and the other on the next higher range, will indicate if the meter is having a loading effect on the circuit. If the two readings are approximately the same, the meter is not causing appreciable voltage variations and the higher reading may be accepted as the true voltage. If the two readings differ considerable, the true voltage may be found by the use of the following formula:

$$E = \frac{E_2 - E_1}{\frac{E_1 R}{E_2} - 1} + E_2$$

where E is the true voltage

E_1 is the lower of the two voltage readings

E_2 is the higher of the two voltage readings

R is the ratio of the higher voltage range to the lower voltage range

To illustrate the application of the correction formula, the following conditions are assumed:

1. A reading of 22 volts was obtained between two terminals with the meter on the 0–30 volt scale.
2. A reading of 82 volts was obtained from the same terminals when the meter was switched to the 0–300 volt scale.

The true voltage may be found as follows:

$$E = \frac{82 - 22}{\frac{22}{82} \cdot 10 - 1} + 82$$

$$E = 119 \text{ volts}$$

A-C Voltmeter

The selection of an a-c voltmeter is more difficult in that frequency and waveform of the voltage being measured must be taken into consideration. Although some a-c voltmeters react to the peak value and others to the average value, most a-c voltmeters are calibrated to indicate effective (r.m.s.) values of voltage. This is because effective values are generally more useful. (R.m.s. is explained in *Basic Electricity*, NavPers 10086.) The relationship of peak, r.m.s. or effective, and average values of voltage is illlustrated in figure 2–1.

Multimeters capable of measuring a-c voltages utilize conventional d-c meter movements and multipliers plus

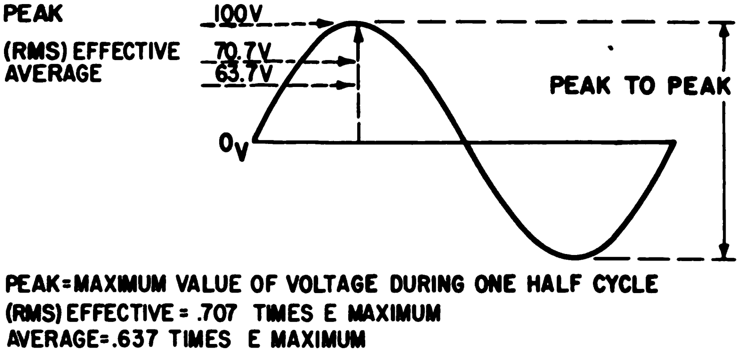

PEAK
(RMS) EFFECTIVE
AVERAGE
100V
70.7V
63.7V
0V
PEAK TO PEAK
PEAK=MAXIMUM VALUE OF VOLTAGE DURING ONE HALF CYCLE
(RMS) EFFECTIVE = .707 TIMES E MAXIMUM
AVERAGE=.637 TIMES E MAXIMUM

Figure 2–1.—Illustration of peak, effective, and average voltage.

metallic oxide rectifiers to change the a.c. to d.c. Most multimeters have an accuracy of 2 to 5 percent at low frequencies. However, the shunt capacity of the metallic oxide rectifiers affects the accuracy of the multimeter as the frequency of the voltage being measured increases. For most multimeters the accuracy decreases approximately ½ percent of 1,000 c.p.s. When the frequency gets above the audio range, the voltage reading is no longer usable. However, for rough readings the multimeter may be sufficiently accurate for most equipments. Where accuracy at the higher frequencies is desired, an A-C VACUUM TUBE VOLTMETER should be used. Although many d-c vacuum tube voltmeters have an a-c voltage function, they use the conventional metallic rectifier circuits, mentioned above.

For measuring a-c voltages such as the aircraft's power supply, the electrodynamometer or iron vane-type meter will give the most accurate measurement. Though the electrodynamometer and the iron vane meters are extremely accurate, their low input impedance makes their use prohibitive in most electronic circuits. Their use should also be restricted to low frequency applications and to circuits that are not affected by meter loading.

USE OF BALANCED BRIDGES

As stated previously in this chapter, an instrument employing a bridge circuit should be used in the measurement of resistance, capacitance, and inductance where a high degree of accuracy is desired. Bridge circuits are used in both a-c and d-c instruments and both types shall be discussed in this section.

Use of D-C Bridges

A type of circuit that is widely used for precision measurements of resistance is the Wheatstone bridge. This type bridge is discussed in detail in *Basic Electricity*, NavPers 10086. We shall discuss only its use in determining a value of resistance for an unknown resistor. The circuit diagram of a Wheatstone bridge is shown in figure 2–2.

In figure 2–2, R_1, R_2, and R_3 are precision variable resistors and R_x is the resistor whose value is unknown. The galvanometer G is inserted across terminals b and d to indicate the condition of balance. When the bridge is properly balanced there is no difference of potential between terminals b and d. Thus, the galvanometer deflection, when the switches S_1 and S_2 are closed, will be zero.

The operation of the bridge is explained in a few logical

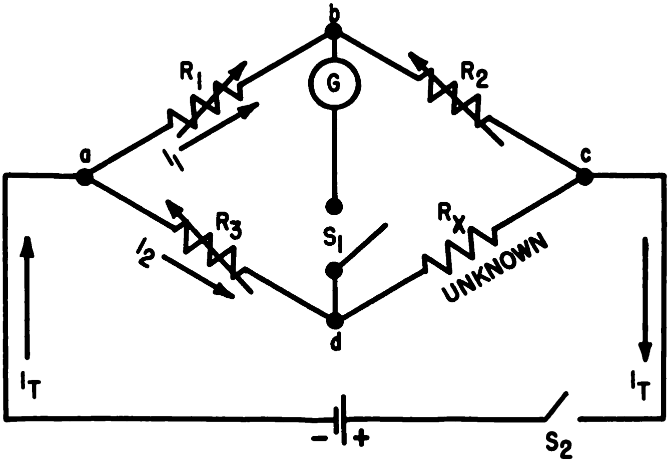


Figure 2–2.—D-c Wheatstone bridge circuit.

steps. When the switch to the battery S_2 is closed, current will flow from the negative terminal of the battery to point *a*. Here the current will divide as in any parallel circuit, a part of it passing through R_1 and R_2 and the remainder passing through R_3 and R_x. The two currents, labeled I_1 and I_2, unite at point *c* and return to the positive terminal of the battery. The value of I_1 depends on the sum of resistances R_1 and R_2 while the value of I_2 depends on the sum of resistances R_3 and R_x. R_1, R_2, and R_3 are adjusted so there will be no deflection of the galvanometer needle when both switches are closed. Thus, there is no difference of potential between points *b* and *d*.

This means that the voltage-drop across R_1 (E_1) is the same as the voltage-drop across R_3 (E_3). By similar reasoning, the voltage-drops across R_2 and R_x, that is E_2 and E_x, are also equal. Expressed algebraically,

$$E_1 = E_3$$

or $$I_1R_2 = I_2R_3$$

and $$E_2 = E_x$$

or $$I_1R_2 = I_2R_x$$

Dividing the voltage-drop across R_1 and R_3 by the respective voltage-drop across R_2 and R_x,

$$\frac{I_1R_1}{I_2R_2} = \frac{I_2R_3}{I_2R_x}$$

Simplifying

$$\frac{R_1}{R_2} = \frac{R_3}{R_x}$$

$$R_x = \frac{R_2R_3}{R_1}$$

The resistance values of R_1, R_2, and R_3 are readily determined from the markings on the standard resistors, or from the calibrated dials if a dial-type bridge is used. Then, after the bridge has been properly balanced, the unknown resistance may be determined by using the formula.

Use of A-C Bridges

There is a wide variety of a-c bridge circuits that may be used for the precision measurements of resistance, capacitance, and inductance. A typical bridge used by the Navy is the ZM–11/U. It is a very flexible test instrument capable of determining values of resistance, capacitance, and inductance over a wide range. A technician using a bridge such as this will need a knowledge of its operation. The discussion of the a-c bridge will be by function.

A-C RESISTANCE BRIDGE.—The Wheatstone bridge discussed previously under d-c bridge circuits is also applicable to circuits utilizing a.c., as shown in figure 2–3.

As shown in figure 2–3, an a-c signal generator is used as the source of voltage. Current from the generator G passes through resistors R_1 and R_2, which are known as the ratio arms, and through R_s and R_x. R_s is an adjustable standard resistance and R_x is the unknown resistance. When the voltage-drops across R_1 and R_s are equal, the voltage-drops across R_2 and R_x are also equal, and no dif-

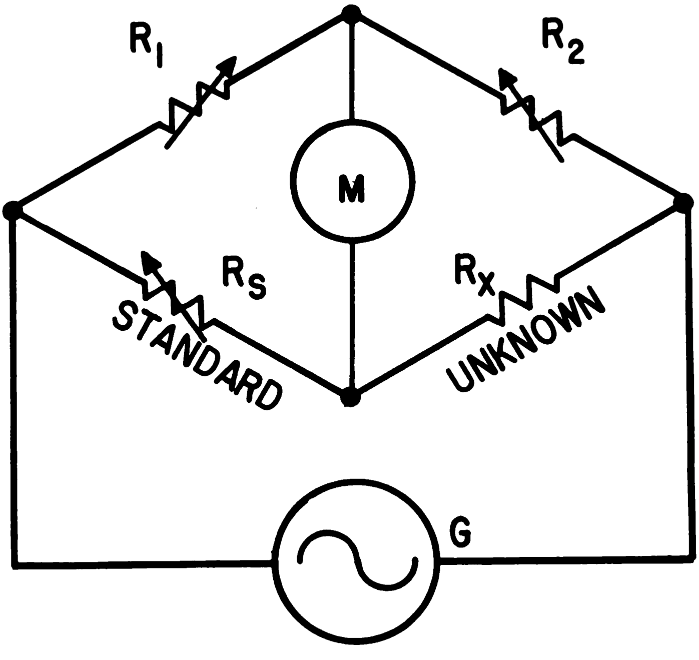


Figure 2–3.—A-c resistance bridge circuit.

ference of potential exists across the meter. As discussed in the section on d-c bridges, when no voltage appears across the indicating device, the following ratio is true:

$$\frac{R_1}{R_2}=\frac{R_s}{R_x}$$

and

$$R_x=\frac{R_2}{R_1}\cdot R_s$$

It is necessary to select the proper resistance values of R_1, R_2, and R_s so that the meter will remain centered when power is applied. With these values of resistance known, the value of the unknown resistance may be found.

A-C CAPACITANCE BRIDGE.—The value of an unknown capacitance C_x may be determined by the capacitance bridge contained in the ZM–11/U, which is shown in simplified form in figure 2–4. The ratio arms, R_1 and R_2, are ac-

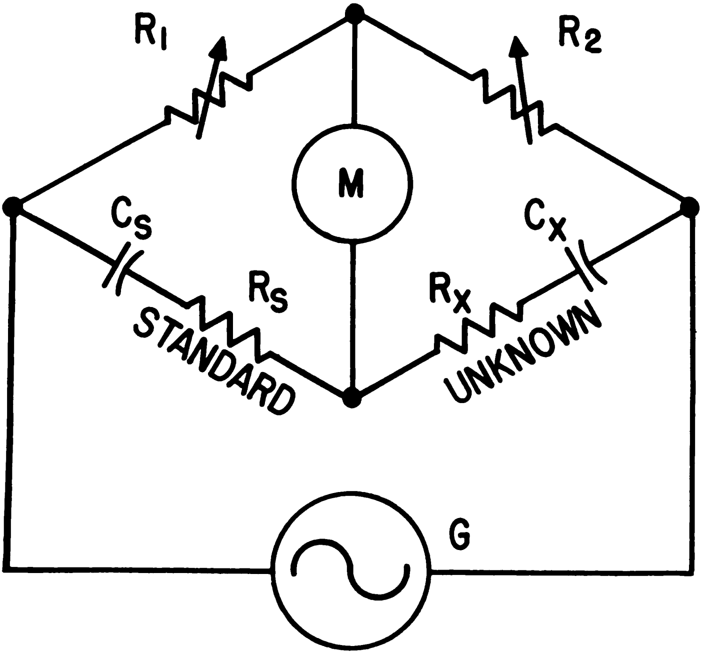


Figure 2–4.—A-c capacitance bridge.

curately calibrated resistors. C_s is a standard capacitor whose capacitance is known, R_s is the equivalent series resistance of the standard capacitor, and R_x is the equivalent series resistance of the unknown capacitor.

With the a-c signal applied to the bridge, R_1 and R_2 are varied until a zero reading is seen on the meter. Zero deflection indicates that the bridge is balanced. (NOTE: In actual practice the variables are adjusted for a minimum reading since the phase difference between the two legs will not allow a zero reading.) Since current varies inversely with resistance and directly with capacitance, an inverse proportion exists between the four arms of the bridge. Thus,

$$\frac{R_1}{R_2}=\frac{C_x}{C_s}$$

or

$$C_x=\frac{R_2}{R_1}\cdot C_s$$

Since R_1 and R_2 are expressed in the same units, $\frac{R_1}{R_2}$ becomes a simple multiplication factor. This equation will give a numerical value for C_x and the answer will be in the same units as C_s (farad, microfarad, etc.).

Similarly, the following direct proportion exists between the four arms of the bridge:

$$\frac{R_1}{R_2}=\frac{R_s}{R_x}$$

or

$$R_x=\frac{R_2}{R_1}\cdot R_s$$

Thus, the unknown resistance and capacitance, R_x and C_x, can be estimated in terms of the known resistance R_1, R_2, and R_s and the known capacitance C_s.

INDUCTANCE BRIDGE.—The value of an unknown inductance L_x may be determined by means of the simple bridge circuit shown in figure 2–5. The ratio arms R_1 and R_2 are accurately calibrated resistors. L_s is a standard inductor whose inductance is known, R_s is its resistance. R_x represents the resistance of the unknown inductor.

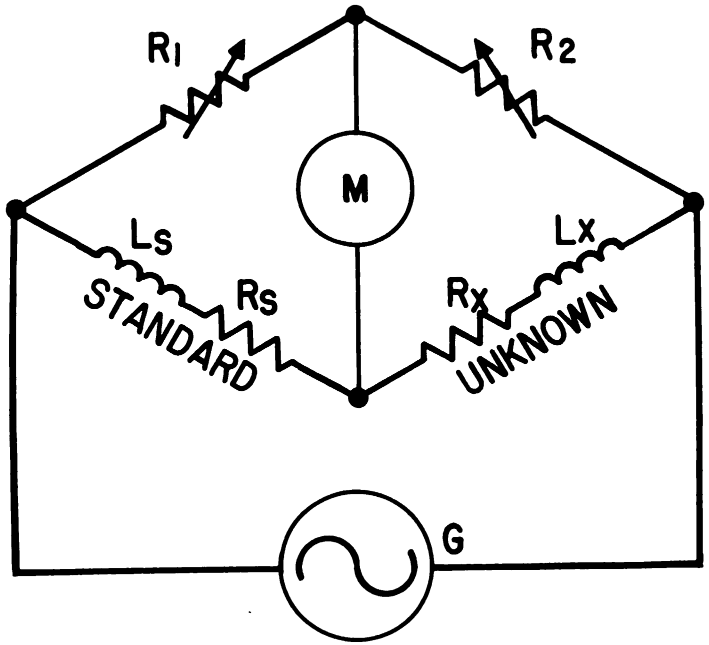


Figure 2–5.—A-c inductance bridge.

Referring to figure 2–5, the a-c signal is applied to the bridge while the two variable resistors R_1 and R_2 are adjusted for a minimum or zero deflection of the meter, indicating a condition of balance. When the bridge is balanced,

$$\frac{R_1}{R_2}=\frac{L_s}{L_x}$$

or

$$L_x=\frac{R_2}{R_1}L_s$$

and

$$\frac{R_1}{R_2}=\frac{R_s}{R_x}$$

or

$$R_x=\frac{R_2}{R_1}R_s$$

Thus, the unknown resistance and inductance can be estimated in terms of the known resistance R_1, R_2, and R_s and the known inductance L_s.

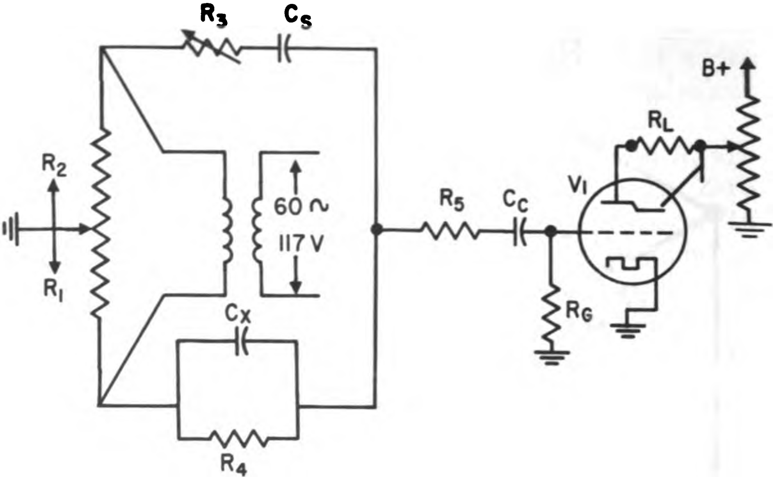


Figure 2–6.—Simplified schematic of impedance bridge.

IMPEDANCE BRIDGES.—In impedance bridges the relation between reactance and resistance in one or more arms of the bridge is variable in order to allow adjustment of the phase and magnitude of the voltage appearance across the bridge when obtaining a balance. Impedance bridges permit more accurate measurements of inductance and capacitance than the bridge circuits previously described. However, their operation is very similar as will be shown in the discussion that follows. A typical impedance bridge circuit connected as a capacitance bridge is illustrated in figure 2–6.

When the bridge circuit shown in figure 2–6 is balanced by adjusting the two variable resistors R_1 –R_2 and R_3, there is no a-c voltage developed across the input of the indicator tube V$_1$, thus the shadow angle is maximum. (The MAGIC EYE tube is discussed in detail in chapter 2 of *Basic Electronics*, NavPers 10087.) Any slight unbalance produces an a-c voltage which causes a grid leak bias to be developed on the grid of V_1. The increased grid voltage will cause reduced plate current of V_1, thus reducing the shadow angle. In the impedance bridge it is not sufficient to have equality of voltage drops in the ratio arms, but in addition the phase angle between current and voltage in each arm containing inductance or capacitance must be equal in order to obtain a balance.

The balance is obtained by adjusting R_3, the variable resistor in series with the standard or known capacitor. When a balance is obtained, the current in R_1 is equal to that in R_2 and the current through C_s is equal to the current in the parallel circuit of C_x and R_4. Thus, when the bridge is balanced the shadow angle is maximum and the following relationship exists:

$$\frac{C_x}{C_s}=\frac{R_2}{R_1}-\frac{R_3}{R_4}$$

or

$$C_x=C_s\left(\frac{R_2}{R_1}-\frac{R_3}{R_4}\right)$$

Substitution of numerical values in the above formula will give a value for C_x.

USE OF THE CATHODE-RAY OSCILLOSCOPE

The operation and operating controls of a general-purpose oscilloscope were discussed in *Aviation Fire Control Technician 3*, NavPers 10388. This instrument is suitable for observation of waveforms in circuits involving low frequencies. However, as your work advances to the more complex equipment involving much higher frequencies, it becomes necessary to use more complex test equipment.

Oscilloscope OS–26/USM–24

An oscilloscope capable of displaying waveforms found in the more complex aviation fire control equipments is the AN/USM–24. The AN/USM–24 is a portable test set for displaying a luminous plot of time variations of a voltage pulse or wave with self-contained means for measuring its duration, displacements, and instantaneous magnitude. The test set consists of Oscilloscope OS–26/USM–24, Oscilloscope Cover CW–268/USM–24, and numerous accessories. (NOTE: The number of the cover is not important, but it is important to know that the complete test set carries a different number than the oscilloscope alone.)

Operating controls and terminals.—All operating controls and terminals of the OS–26/USM–24 oscilloscope are located on the oscilloscope's front panel and in the rear of the combination case as shown in figure 2–7 (A) and (B). The purpose of each control and terminal is explained briefly. The figure and the legend should be studied in

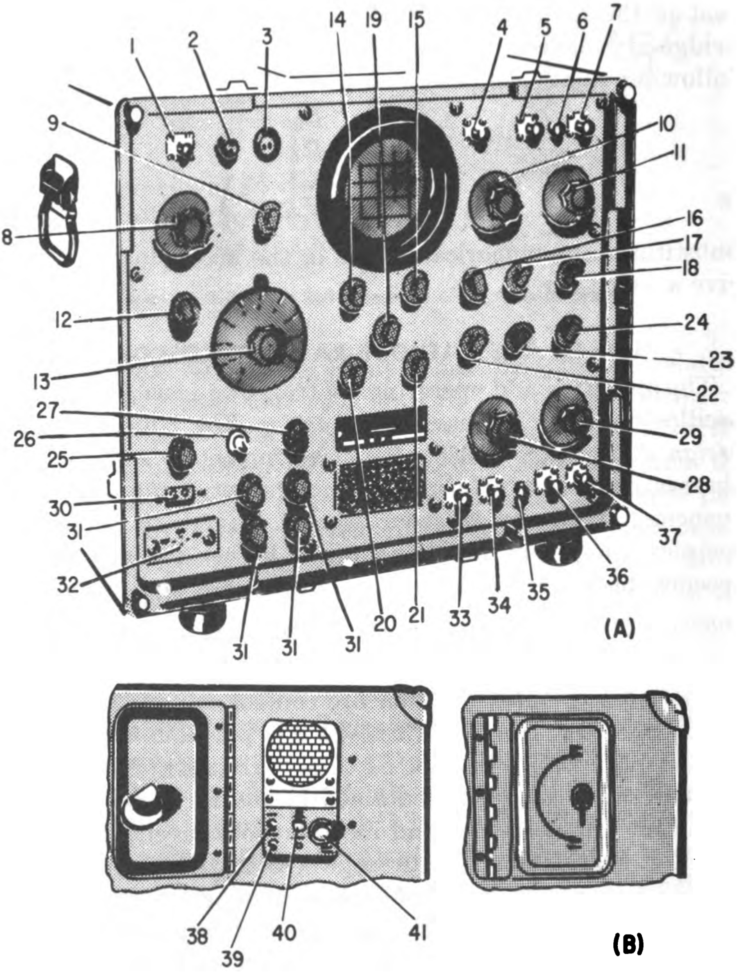


Figure 2–7.—Oscilloscope OS–26/USM–24. (A) Front panel; (B) rear view.

Nomenclature for figure 2–7 (A) and (B)

1. V INPUT—Connector for connecting external signal to the vertical amplifier.
2. GND—Binding post for external ground.
3. PROBE—Connector for test probes.
4. H OUTPUT—Connector making the horizontal signal at one plate of the cathode-ray tube available for external use.
5. H INPUT—Connector for connecting external signal to the horizontal amplifier.
6. GND—Binding post for external ground.
7. SYNC INPUT—Connector for connecting external synchronization signal to sync amplifier.
8. V MULTIPLIER—Six-position rotary switch for attenuating vertical input signal up to 300 to 1.
9. V GAIN—Potentiometer for adjusting the gain of vertical amplifier. The total range variation is up to 6 to 1.
10. SWEEP μ S—Six-position rotary switch for selecting various sweep lengths.
11. SYNC—Four-position rotary switch for selecting internal or external modes of sync operation.
12. CAL—Two-position spring return rotary switch for calibration of vertical amplifier.
13. CAL VOLTS—Potentiometer providing accurate voltage necessary for calibration of vertical amplifier.
14. V POS—Potentiometer for adjusting the trace on cathode-ray tube along vertical axis.
15. H POS—Potentiometer for adjusting the trace on cathode-ray tube along horizontal axis.
16. SWEEP DELAY OUT-IN—Two-position rotary switch for selecting undelayed or delayed sweeps.
17. FINE SWEEP—Potentiometer for adjusting the sweep lengths within ranges of SWEEP μ S.
18. SYNC—Potentiometer for adjusting the magnitude and polarity of synchronizing signal.
19. SCALE ILLUMINATION—Rheostat with snap switch for adjusting the brightness of graduated scale as well as means for complete dimming.
20. FOCUS—Potentiometer for focusing the trace on the cathode-ray tube.
21. BEAM—Rheostat for controlling the intensity of the trace on the cathode-ray tube.
22. SWEEP DELAY—Potentiometer for selecting desired sweep delay.
23. H GAIN—Potentiometer for adjusting the gain of horizontal amplifier.
24. SWEEP STABILITY—Potentiometer controlling the sensitivity of sweep circuitry as well as selecting either periodic or trigger mode of operation.
25. HEATER INDICATOR—Indicator light for internal heater.
26. HEATER-OFF-POWER—Three-position toggle switch for turning the oscilloscope on, off, or standby internal ambient heater.
27. POWER INDICATOR—Indicator light for power on or off.
28. MARKER μ S—Six-position rotary switch for selecting the desired markers applied to intensify the beam of CRT or for applying external signal from beam mod connector.
29. TRIGGER PPS—Six-position rotary switch for selecting desired internal trigger rate.
30. POWER INPUT—Connector for applying external power through power cable.
31. FUSE (4)—Two are four-ampere fuses for oscilloscope protection and two are receptacles for spares.
32. VOLTAGE SELECTOR SWITCH—Three-position rotary switch for selecting proper line voltage input. The switch cannot be operated unless power cord is removed.

Nomenclature for figure 2–7 (A) and (B)—Continued.

33. **CAL OUTPUT—Connector providing externally a calibration signal generated within the oscilloscope.**
34. **BEAM MOD—Connector for connecting external signal to modulate beam intensity.**
35. **GND—Binding post for external ground.**
36. **and 37. TRIGGER OUTPUT—Connectors providing externally trigger pulses of either polarity as generated within the oscilloscope.**
38. **GND—Terminal for external ground.**
39. **V-PLATE—Terminal for connecting external signal directly to one vertical plate of the cathode-ray tube through use of NORMAL-V DIRECT switch.**
40. **NORMAL-V DIRECT—Two-position slide switch for connecting either external signal from V-PLATE connector or internal signal to one vertical deflection plate.**
41. **INTERLOCK SWITCH—Push interlock switch, normally closed, used as a safety device so that oscilloscope will not operate unless the rear door is opened for ventilation.**

detail in order to become familiar with the various controls and terminals.

Voltage limitations.—Before using any oscilloscope, it is important that the technician know the approximate voltage amplitude of the signal to be observed and the d-c voltage (steady state) level of the test point. The maximum voltage to which an oscilloscope is connected should never exceed that recommended by the *Handbook of Operating Instructions* for the particular test instrument. The voltage limitations listed in table 2–1 for the OS–26/USM–24 are typical for oscilloscopes of this type. The figures indicated are total voltages which include not only the signal component but the steady state (d.c.) as well.

In noting the figures in table 2–1, it should be remembered that the exact voltage quantities may be found in the appropriate handbook. It is important to remember that by using different probes in connecting the inputs to the oscilloscope, voltages of a large range may be applied without damage to the equipment. In cases when it may become necessary to observe waveforms involving voltages in excess of those previously stated, a voltage divider may be used.

Waveform observation.—In the maintenance of aviation fire control equipment, it is frequently necessary to observe

Table 2–1.—Voltage limits.

Connector	Condition	Signal peak voltage	Total peak voltage
V INPUT		150	400
V INPUT	With Test Lead CG–883/USM–24.	600	600
V INPUT	With Test Lead CG–944/AP.	2	400
V DIRECT		150	+600 −150
H INPUT		40	400
SYNC INPUT		150	150
SYNC INPUT	With Test Lead CG–883/USM–24.	450	600
BEAM MOD		50	400
BEAM MOD	With Test Lead CG–883/USM–24.	450	600
TRIGGER PLUS			D-c coupled
TRIGGER MINUS			+600 −200

waveforms at various test points within the equipment. First, in taking waveforms, it is necessary to prepare the oscilloscope and the equipment. The oscilloscope must be properly grounded to protect the operator from dangerous voltages that may result from a part breakdown. Next, the technician must decide if the oscilloscope sweep is to be triggered or synchronized; and if synchronized, whether to use external or internal sync.

To present a stationary pattern on the screen of the oscilloscope, the frequency of the waveform to be observed must be equal to or some multiple of the frequency of the sawtooth sweep voltage. If this condition does not exist, the observed waveform will appear to drift across the screen. The process by which the sweep frequency is adjusted to conform to that of the observed waveform is called sweep synchronization.

Many times it is desired to observe more than one cycle of the input waveform. To do this, the sweep frequency must be adjusted until the input frequency is some multiple of the sweep frequency. If two cycles are to be displayed, the sweep frequency must be one-half that of the input frequency. If three cycles are to be observed, the sweep frequency must be one-third that of the input frequency. The time required for the complete sweep waveform must be equal to the time of the number of cycles to be displayed.

To observe waveforms utilizing the OS–26/USM–24, the controls must be set (assuming that the oscilloscope has been adjusted for proper focus, beam position, and beam intensity, and the signal and sync test leads are connected to their respective connectors) as follows:

1. By means of the SWEEP μ S switch and FINE SWEEP potentiometer, set the sweep time base to the proper range based on the number of cycles to be observed.
2. Set the SYNC selector switch to the desired synchronization source.
3. Set the H GAIN about halfway.
4. Rotate the SYNC control through its entire range and

note the null point; set the control at this position. (NOTE: The null point is the point at which the horizontal sweep disappears.)

With the controls thus adjusted, the oscilloscope may be operated in the REPETITIVE mode by rotating the SWEEP STABILITY control in a clockwise direction until a horizontal trace appears. To check your adjustment, slowly rotate the SYNC control through its null point. The horizontal trace should remain during this rotation.

To operate the oscilloscope in a TRIGGERED mode, set the SYNC control to the null point and rotate the SWEEP STABILITY control in a counterclockwise direction until the horizontal trace disappears. Check your adjustment by rotating the SYNC control away from the null point—the horizontal trace should reappear.

Once the mode of operation has been established by the proper setting of the SWEEP STABILITY control, the sweep can be controlled by the SYNC switch as follows:

SYNC switch position	*Source of signal*
INT-SIGNAL	Sweep internally synchronized or triggered by the signal.
EXT-LOW or EXT-HI	Sweep externally synchronized or triggered. (NOTE: EXT-LOW is used if the synchronizing signal is less than 5 volts.)
INT-TRIG	Sweep synchronized or triggered from internal trigger generator. (NOTE: These pulses are highly accurate in frequency and are available at 50, 300, 800, 2,000, or 5,000 pulses per second as selected by the TRIGGER PPS switch.)

When it is necessary or desired to observe a particular portion of the trace, the SWEEP DELAY switch is turned to the IN position. This allows a 10 percent portion of the trace to be examined in detail. This 10 percent portion is expanded to occupy the full length of the screen which enables the SWEEP DELAY control to be adjusted until the desired portion of the trace appears on the screen of the CRT.

The AQ will find it necessary during troubleshooting and alinement of various fire control equipment to use the oscilloscope for direct measurements of voltage amplitude and signal duration or time.

VOLTAGE MEASUREMENTS.—The amplitude of any signal displayed upon the screen of the cathode-ray tube may be measured directly in peak voltage by employing the calibration circuit contained in the oscilloscope. To measure the voltage amplitude of a signal, set the SWEEP μ S switch to H AMP position to eliminate optical confusion in the horizontal plane. Turn the SCALE ILLUMINATION control clockwise until the scale divisions are plainly visible. Note the number of vertical divisions which the signal occupies. Hold the CAL switch in the ON position and adjust the CAL VOLTS control until the calibration signal occupies the same number of vertical divisions. The peak voltage is the reading on the CAL VOLTS dial multiplied by the V MULTIPLIER switch setting. The waveform of the calibrating voltage is shown in figure 2–8.

It should be noted that the CAL VOLTS dial is calibrated in peak-to-peak voltage. If r.m.s. voltage is desired, the computed voltage must be divided by 2.83.

TIME MEASUREMENTS.—The time duration of signals or portions of signals displayed on the cathode-ray screen may be measured by means of accurately timed marker pulses which appear as intensified dots along the trace as shown in figure 2–9. The marker pulses are generated in the oscilloscope and are available as follows: 0.2 μ S, 1.0 μ S,

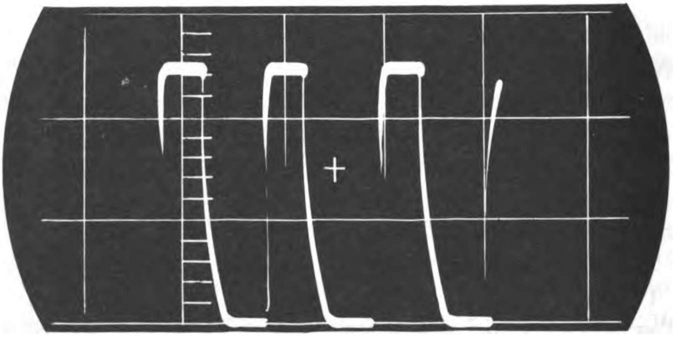


Figure 2–8.—Calibration voltage waveform.

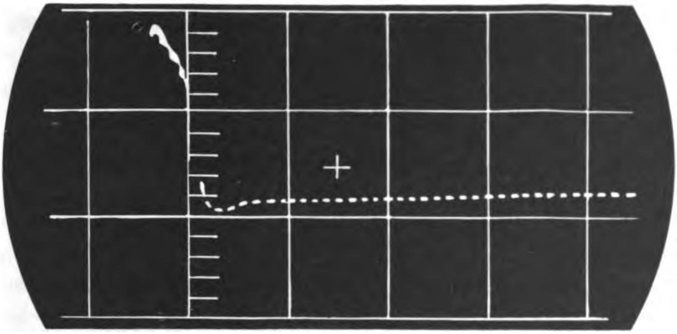


Figure 2–9.—Pulse and time markers.

10 μ S, 100 μ S, and 500 μ S. However, the accuracy of time measurements is limited below 1.0 μ S. They are applied to the trace by setting the MARKER μ S switch to the appropriate range and adjusting the BEAM control until the markers are clearly defined.

An ATTENUATING PROBE is provided with the OS–26/USM–24. It is used to introduce losses of approximately 10 to 1 and increase the input impedance by 10. It is employed when the input signal is sufficiently large to overdrive the amplifier and distort the scope presentation. The probe may also be used to reduce the total capacitive shunting effect on a circuit under test.

A SPECIAL TEST LEAD having an input impedance of 1 megohm and capable of handling voltages up to 2 volts r.m.s. is also provided with the oscilloscope. It is employed where the signal under test is small in amplitude and the shunt capacity of the oscilloscope would cause a loading effect on the circuit under test.

Frequency Comparison

Measurement of frequency can be accomplished with the oscilloscope by comparing an unknown frequency with a standard or known frequency. The procedure involves the production of Lissajous patterns on the oscilloscope. These patterns, or figures, are traced on the screen when the linear sweep voltage is switched off and sine-wave voltages are applied both to the horizontal and to the vertical deflection plates.

The development of a typical Lissajous pattern is shown

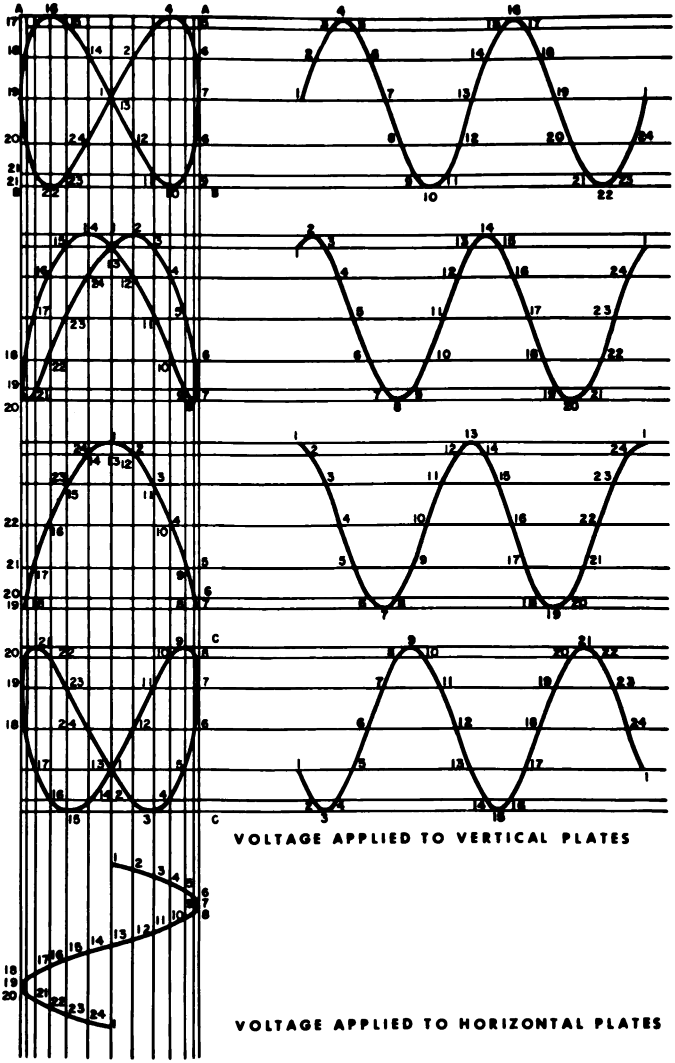

A
B
C
VOLTAGE APPLIED TO VERTICAL PLATES
VOLTAGE APPLIED TO HORIZONTAL PLATES

Figure 2–10.—Lissajous figures for 1:2 ratio.

in figure 2–10. In the figure, the frequency of the signal applied to the vertical plates is twice that applied to the horizontal plates, giving a frequency ratio of 1 : 2.

In the pattern shown, the figure changes in appearance with changes in phase angle of the two voltages. However, one fact is common to all. The number of times the patterns touch a horizontal line drawn along the top of the figures is two in each case. Also, the patterns all touch a vertical tangent line one time. The number of points of tangency to such horizontal and vertical lines indicates the ratio of the two frequencies. The relation of the frequency ratio to the pattern may be stated as follows:

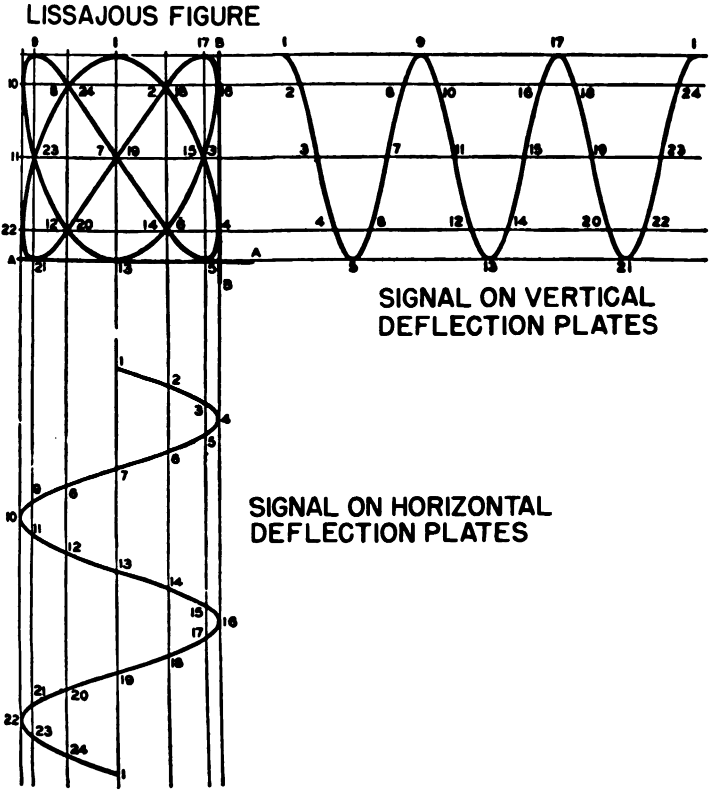

LISSAJOUS FIGURE
SIGNAL ON VERTICAL DEFLECTION PLATES
SIGNAL ON HORIZONTAL DEFLECTION PLATES
A
B

Figure 2–11.—Lissajous figure for 2:3 frequency ratio.

$$\frac{\text{Frequency applied to horizontal plates}}{\text{Frequency applied to vertical plates}} = \frac{\text{Number of points of tangency to a vertical line}}{\text{Number of points of tangency to a horizontal line}}$$

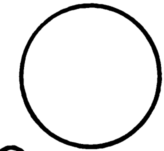
In figure 2–11, the pattern touches the horizontal line A–A three times. It touches the vertical line B–B two times. Hence, the ratio of the applied frequencies is 2:3. If one of the frequencies is known, the other can be found. For example, if the horizontal frequency is 600 cycles per second, the vertical frequency can be found from the ratio as follows:

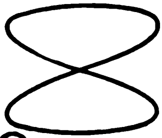
$$\frac{600}{f} = \frac{2}{3}$$

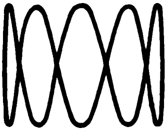
$$f = \frac{3}{2} \times 600$$

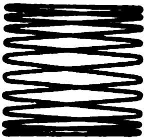
$$f = 900 \text{ cycles per second.}$$

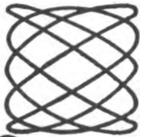
In measurement of unknown frequencies, the output of a calibrated oscillator or signal generator can be used as


① RATIO 1:1


② RATIO 2:1


③ RATIO 1:5


④ RATIO 10:1


⑤ RATIO 5:3

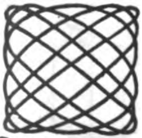

⑥ RATIO 6:5

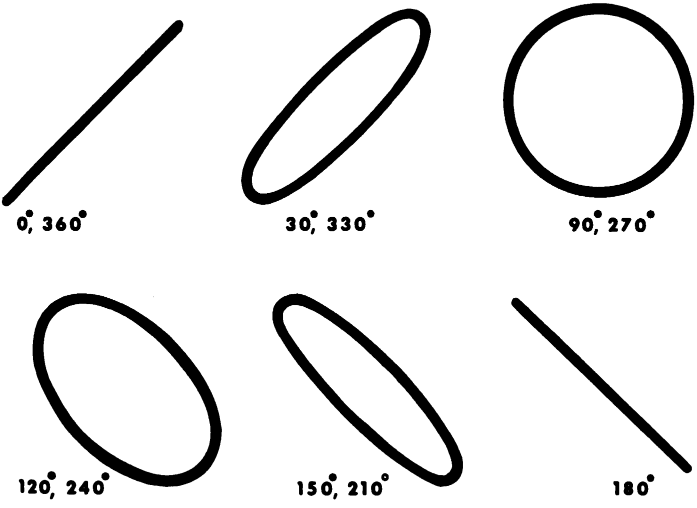
Figure 2–12.—Lissajous patterns for various ratios.

the standard frequency and comparison made with it by means of the oscilloscope figure.

In figure 2–12, the patterns resulting from various frequency ratios are shown. The circle is the simplest of Lissajous figures, and results when the applied frequencies are equal and differ in phase by either 90 or 270 degrees. In patterns of frequencies which are almost equal, the traces become rather complex. Also, patterns of ratios greater than 10 to 1 are difficult to interpret.

In figure 2–13, the figures are indications of phase difference. If the applied frequencies are equal and in phase, the trace is a straight line tilted at 45 degrees. When the phase angle is increased, the line opens into an ellipse, or oval; and at exactly 90 (or 270) degrees, a circle appears. At 180 degrees of phase difference, a straight line is formed which is tilted at 135 degrees. In the patterns shown, the applied signals are of equal amplitude. If the voltages are not equal, the pattern never becomes circular, but is elliptical for angles different from 0 or 180 degrees.

Your ability as an Aviation Fire Control Technician will, to a great extent, depend on your ability to operate



0°, 360° 30°, 330° 90°, 270°

120°, 240° 150°, 210° 180°

Figure 2–13.—Oscilloscope patterns which indicate phase difference.

the oscilloscope properly and know how to utilize it. An oscilloscope such as the one discussed in this chapter is capable of displaying more information in a few seconds than other instruments could in hours. However, you must be able to interpret the information before any use can be made of it. Use the oscilloscope and use it correctly. It is one of your most dependable test instruments. A *Handbook of Operating Instructions* is provided with each type of oscilloscope used by the Navy. Obtain one for the particular oscilloscope you are to use and study it thoroughly.

USE OF SIGNAL GENERATORS

In the maintenance of aviation fire control equipment, it is often necessary to employ standard source of a-c energy, both audiofrequency and radiofrequency. These sources are called SIGNAL GENERATORS. They are used in testing, troubleshooting, and alinement of fire control devices such as radar receivers, timing circuits, and amplifiers of various types.

The principal function of a signal generator is the production of an alternating voltage of the desired frequency and amplitude which has the necessary modulation for the test or measurement in question. It is very important that the amplitude of the generated signal be correct; and in many generators, output meters are included in the equipment so that the output may be adjusted and maintained at a standard level over a wide range of frequencies.

When using the signal generator, the output test signal is coupled into the circuit being tested and its progress through the equipment is traced by the use of high-impedance indicating devices such as vacuum tube voltmeters or oscilloscopes. In many signal generators, calibrated networks of resistors, called ATTENUATORS, are provided. These are used to regulate the voltage of the output signal and also provide correct impedance values for matching the input impedance of the circuit under test. Accurately calibrated attenuators are desirable since the signal strength must be regulated to avoid overloading the circuit receiving the signal.

There are many types of signal generators. It is possible to classify them roughly by frequency into audio generators, generators of both the audio and video ranges, radiofrequency generators, frequency-modulated RF generators, and special types which combine all of these frequency ranges.

In almost all of these types, electron tube oscillators are used to produce the initial signal. In order to achieve accurate results in the use of the signal source, it is necessary to allow the oscillator circuits to reach a condition of stable operation before applying the output. This condition is reached when the tubes and circuit elements attain the temperature at which the instrument was calibrated. A preliminary warmup should always be given the generator when accurate and stable signals are desired. The minimum warmup time for the generator is given in the *Handbook of Service Instructions.* The general properties and functions of signal generators were discussed in *Basic Electronics*, NavPers 10087. In the following sections, there is a discussion of the types of generators most commonly used by the Aviation Fire Control Technician.

Audio Signal Generators

Audio signal generators produce stable audiofrequency signals which may be used for testing aviation fire control circuits. A typical audio oscillator supplied by the Navy for fire control maintenance is the TS–382B/U. It should be remembered that the discussion to follow, although based on the use of a specific test equipment, will, in general, be applicable to other signal generators of its type.

The Audio Oscillator TS–382B/U (fig. 2–14) is a laboratory or shop device which generates a-c voltages ranging from 20 to 200,000 cycles per second at amplitudes which may be varied continuously from 0 to 10 volts. Its output frequency and amplitude are very accurate, making the instrument suitable for the measurement of gain and distortion in electronic circuits such as servo amplifiers.

The instrument is equipped with the necessary cables,

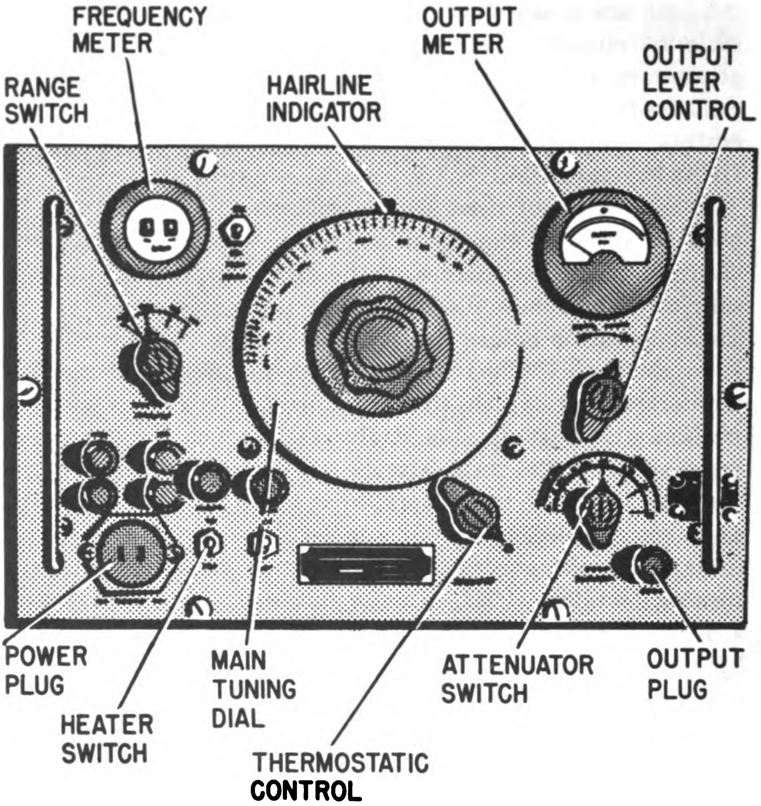


Figure 2–14.—Audio Oscillator TS–382B/U.

adapter connectors, and a dummy load. The adapter connector is used when the external load is approximately 1,000 ohms or less. The dummy load, which contains a 1,000–ohm resistor, is used when the external load is of a high impedance so that the oscillator can be operated into its rated load.

Selecting frequency.—Any frequency from 20 to 200,000 c.p.s. may be selected by setting the main tuning dial and Frequency Multiplier switch. The setting of the main tuning dial when multiplied by the Frequency Multiplier switch setting equals the output frequency. For example, to select an output frequency of 52,000 c.p.s., set the main tuning dial to 52 and the FREQUENCY MULTIPLIER switch to "X1,000."

SELECTING OUTPUT VOLTAGE.—Voltages from 0 to 10 volts may be obtained by proper use of the OUTPUT CONTROL and OUTPUT MULTIPLIER switch. The OUTPUT MULTIPLIER switch provides a means of connecting one of seven decade steps of an attenuator giving seven multipliers ranging from X10 to X0.00001. For intermediate values of output voltage, the OUTPUT CONTROL is varied so that the output meter reads a voltage that when multiplied by the setting of the OUTPUT MULTIPLIER will give the desired voltage. For example, to obtain an output voltage of 0.04 volts, set the OUTPUT CONTROL for a meter reading of 0.4 volts and the OUTPUT MULTIPLIER to X.1 position.

It should be noted that the calibration of the attenuator is accurate only when the instrument is working into its rated load of 1,000 ohms. Therefore, it is necessary to use the dummy load when the output of the generator is being applied to a high-impedance load.

HANDLING AND STORAGE.—The technician should exercise the same care in handling this equipment as he would in handling any other delicate laboratory equipment. It should be used under shop conditions and protected from high temperature, dust, rain, and other adverse atmospheric conditions. If the instrument has been subjected to conditions of high humidity, the heating elements should be used for at least 1½ hours to dry out the unit before storing. If the oscillator is to be stored for a long period of time, it should be placed in its transit case along with a dehydrating agent (activated silica gel), and the lid of the case should be clamped tightly. The technician should always consult the *Handbook of Service Instructions* for the particular instrument for other storage and handling instructions.

Radiofrequency Signal Generator

The radiofrequency signal generator is an instrument designed to produce stable a-c voltages in the RF range.

It is used to aline and troubleshoot various aviation fire control circuits which operate in the radiofrequency range. Most radiofrequency signal generators are designed to produce an RF signal with some type of modulation. The modulating voltage may be either a sine wave, a square wave, or pulses of varying duration. In some specialized generators, provisions are made for pulse modulation in which the RF signal can be pulsed over a wide range of repetition rates and at various pulse widths. The type of modulation used depends on the application of the particular signal generator. In this section we shall discuss amplitude and frequency-modulated types of RF signal generators.

AMPLITUDE MODULATED.—All amplitude-modulated RF signal generators contain some type of modulator. The modulator is usually a circuit which produces sine-wave modulation of the RF signal. In addition, most generators are provided with connections for use of an external modulating voltage of any desired waveform. Normally, a means of disabling the modulator section is also provided whereby the pure unmodulated signal from the oscillator can be used.

In some RF generators the output circuit contains a calibrated attenuator and an output level meter similar to the one discussed in the section entitled "Audio Signal Generators." Those generators not equipped with both an output meter and attenuator will provide some means of controlling the amplitude of the output voltage.

To select a desired frequency, most RF generators have a tuning control or frequency selector and indicator. The tuning control is adjusted until the desired frequency is obtained as shown on the indicator. The indicator is usually a rotary-type drum and calibrated in megacycles.

To select the percent of modulation, most generators have a MODULATION LEVEL CONTROL and PERCENT MODULATION METER located on the front panel. The output of the signal generator may be modulated up to 100 percent by adjusting the MODULATION LEVEL CONTROL, and the percent of modulation will be indicated on the PERCENT MODULATION METER. The output of the signal generator is fed from the signal generator to the circuit under test through a coaxial cable and, if necessary, an impedance adapter to match the circuit input. The signals are passed through the circuit under test and are normally measured or observed as deflections on an indicator such as a vacuum tube voltmeter or oscilloscope.

The RF signal generator should prove of great value to the AQ in signal tracing and alinement of servo amplifiers and other electronic circuits. Alinement procedures for the various circuits found in aviation fire control equipments will vary and can be found in the equipment's *Handbook of Service Instructions.*

FREQUENCY MODULATED.—Frequency-modulated RF signal generators, often called sweep generators, are widely used for testing frequency-modulated circuits and for visual alinement using an oscilloscope. A frequency-modulated signal is an alternating voltage in which the frequency varies periodically above and below a given center frequency value. The overall frequency change is called the frequency swing. This swing usually occurs at an audio-frequency rate.

The technique of visual alinement consists of applying a frequency-modulated signal to the input of the equipment under test and observing the band pass characteristics of the equipment on an oscilloscope connected to the output. Since the frequency response curve is observed on an oscilloscope, it is necessary to provide a means of indicating frequency along the curve. This is accomplished in most generators internally by a marker generator. The marker generator produces a single frequency signal which is variable for use as a marker signal displayed on the response curve. Most FM generators also include a jack on the front panel to furnish the oscilloscope a horizontal sweep signal identical to the modulating signal of the FM oscillator. This is extremely useful for synchronizing the scope to make waveform observations.

A blanking circuit may also be included in the generator to eliminate one-half of each cycle of the audio modulating signal applied to the FM oscillator. If so, it is possible to establish a base line on the oscilloscope screen so that relative gain measurements can be made.

The selection of the desired output voltage level and the center frequency of the FM sweep oscillator is much the same as in the amplitude-modulated signal generator and will not be discussed further. However, the FM signal generator usually has additional controls for adjusting the amount of sweep signal deviation above and below the center frequency. It also has various knob controlled rotary switches, potentiometers, and variable capacitors to adjust the amplitude and frequency of the marker oscillator, and to adjust the blanking voltage to the oscilloscope. For proper operation of these controls, the *Handbook of Operating Instructions* or *Handbook of Service Instructions* for the particular signal generator should be consulted.

Like the AM signal generator, the AQ will find the FM signal generator very helpful in alinement of servo amplifiers, demodulators, and many other electronic circuits.

USE OF FREQUENCY METERS

The general terminology of frequency meters is discussed in *Basic Electronics*, NavPers 10087, in the section entitled "Frequency Standards." The discussion to follow is to supplement that information and to aid the AQ in the use of these instruments.

A frequency meter is an instrument used to provide a simple, reliable, and accurate means for adjusting or alining the emitted or resonant frequency of emitters and tuned detectors to a desired value. The term **FREQUENCY METER** is sometimes applied to test instruments which measure the frequencies of external signals and have no provisions for emitting a signal. This type of instrument is more properly called a **WAVEMETER.**

Wavemeters

Wavemeters are calibrated resonant circuits used to measure frequency. They are comparatively simple and can be carried about easily. Any type of resonant circuit may be used in wavemeter application. The exact kind of circuit employed depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used for low frequency wavemeters. Adjustable transmission line sections and resonant cavities are used in VHF and microwave instruments.

There are three basic types of wavemeters; namely, absorption, reaction, and transmission. ABSORPTION wavemeters are composed of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use this type of wavemeter is loosely coupled to the circuit to be measured. The resonant circuit of the wavemeter is then adjusted until the current meter shows a maximum deflection. The frequency of the circuit under test is then determined from the calibrated dial of the wavemeter.

The REACTION TYPE derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator, and the resonant circuit of the meter is adjusted until it is in resonance with the oscillator frequency. The setting of the wavemeter dial is made by observing the grid current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter.

The TRANSMISSION WAVEMETER is an adjustable coupling link. When it is inserted between a source of radiofrequency energy and an indicator, energy is transmitted to the indicator only when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are widely used in measuring microwave frequencies.

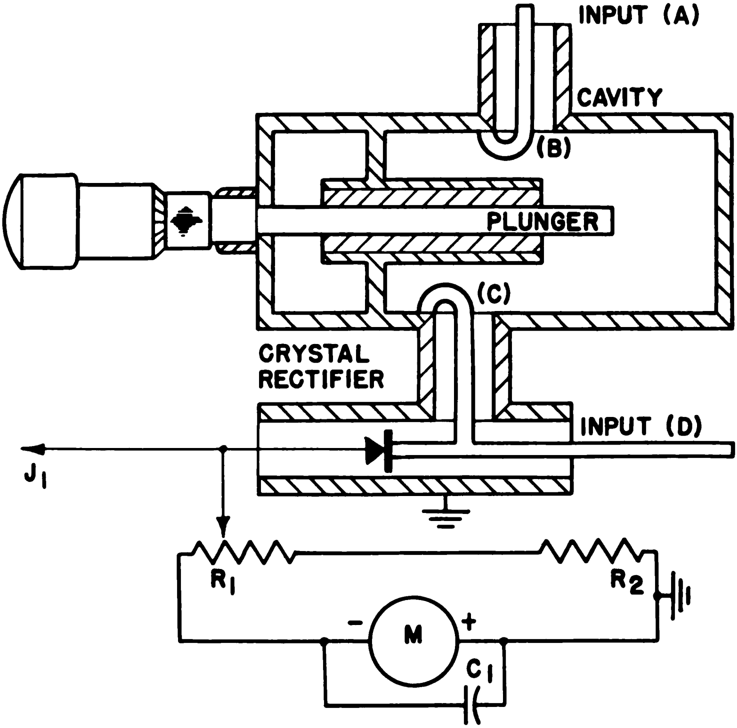


Figure 2–15.—Typical resonant cavity wavemeter.

The wavemeter illustrated in figure 2–15 is the type commonly used for measurement of microwave frequencies.

The device shown in figure 2–15 employs a resonant cavity which effectively acts as a high-*Q* *LC* tank circuit. The resonant frequency of the cavity is varied by means of a plunger which is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity size and increases the resonant frequency. Conversely, increasing the size of the cavity (by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test is fed into the wavemeter through one of two inputs, *A* or *D*. A crystal rectifier then detects or rectifies the signal, and the rectified current is indicated on the current meter *M*.

The instrument illustrated can be used as either a transmission type or an absorption type wavemeter. When used as a transmission wavemeter, the unknown signal is coupled into the wavemeter by means of input *A*. When the cavity is tuned to the resonant frequency of the signal, energy is coupled through coupling loop *B* into the cavity and out through loop *C* to the crystal rectifier where it is rectified and is indicated on the meter. At frequencies off resonance, little or no current flows in the detector and the meter reading is small. Therefore, the micrometer and attached plunger are varied until a maximum meter reading is obtained. The micrometer setting is then compared with a calibration chart supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter is usually used as an absorption type device. Connection is made to the instrument at the input *D*. The RF loop *C* then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the unknown signal, maximum energy is absorbed by the cavity and the current indicated on the meter dips. When the cavity is not tuned to the frequency of the input signal, high current is indicated on the current meter. Therefore, the cavity is tuned for a minimum reading, or dip, in the meter and the resonant frequency is determined from the micrometer setting and the calibration chart.

The potentiometer R_1 is used to adjust the sensitivity of the meter from the front panel of the instrument. J_1 is a video jack and is provided for observing waveforms with a test oscilloscope.

Frequently, the AQ will find it necessary to use the wavemeter in alinement and measurement of frequency in circuits throughout aviation fire control equipment. The proper use of this instrument under all circumstances cannot be covered in this chapter. For detailed instructions consult the *Handbook of Service Instructions* for the equipment involved.

Heterodyne Frequency Meters

A heterodyne frequency meter can be used as a signal generator to supply a signal of moderate power which is extremely accurate in frequency. It can also be used as a wavemeter for determining an unknown frequency or for adjusting an output frequency to a specific value.

The heterodyne type of frequency meter, which contains a reference crystal for more accurate calibration, is typical of the types employed in the maintenance of fire control equipment. This type of instrument usually consists of a heterodyne oscillator, an RF harmonic or distortion amplifier, a crystal-controlled oscillator, a mixer or detector, a modulator, an AF output amplifier, and a means for indicating frequency (in most cases a meter or headphones). Most frequency meters are furnished with a set of calibration charts giving the dial readings for the frequencies listed, together with a table of the crystal harmonics; thus, a complete and accurate frequency coverage over the designed range is provided. Figure 2–16 illustrates a block diagram of a typical heterodyne frequency meter.

In operation, the output of the variable frequency heterodyne oscillator is coupled into the RF harmonic amplifier. When signals are being generated for testing purposes, the output of this harmonic amplifier is coupled to the antenna and the RF coupling connector as shown in figure 2–16. When the signals are being received as an unknown,

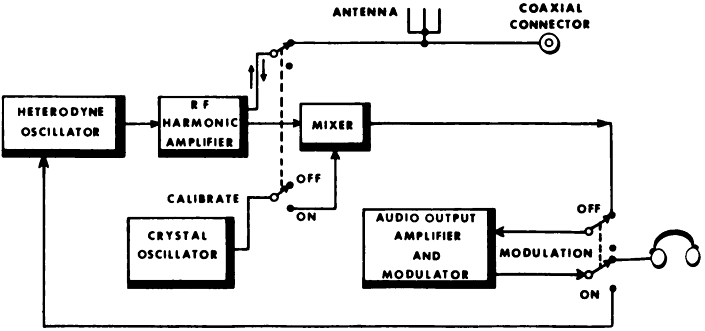


Figure 2–16.—Block diagram of a typical heterodyne frequency meter.

the harmonic amplifier output is coupled to the mixer (detector) tube along with the incoming signal under test.

The crystal-controlled oscillator operates at a fixed frequency, but is also capable of emitting various harmonic frequencies of the crystal for use as check frequencies (check points) for adjusting the heterodyne oscillator, thus insuring more accurate operation. Provisions are usually made within the crystal-controlled oscillator for precise adjustment to its fundamental frequency. When it is desired to make this frequency check, comparison can be made to the standard WWV transmissions broadcast by the Bureau of Standards.

When the mixer is switched to CALIBRATE position, the antenna and coaxial connector (RF input) are disconnected and the heterodyne oscillator output is combined with the output of the crystal oscillator, permitting the calibration, or correction, by the ZERO BEAT method of the variable oscillator for the desired frequency range. When the calibration switch is turned to the OFF position, signals from the antenna are coupled into the mixer along with signals from the heterodyne oscillator, and the zero beat method is then used for the adjustment of the external circuit or equipment under test. ZERO BEAT is defined as heterodyne action with zero frequency difference.

With most frequency meters the audio amplifier has two functions. It amplifies the beat note produced by the mixing of the unknown signal and the calibrated heterodyne oscillator (modulation off), and thus gives a ZERO BEAT in the earphones when the signal of the equipment under test is adjusted to the frequency of the heterodyne oscillator. With the modulation switch in the ON position, the stage serves as an audiofrequency modulator, supplying an AF signal and modulating the RF signal produced by the heterodyne oscillator.

The heterodyne-type frequency meter is used in aviation fire control circuits for various purposes; for example, as a low power RF amplitude-modulated signal generator, in alinement of resonant circuits, for frequency measurements, and many other purposes. It should be evident that the frequency meters are delicate instruments and should be handled as such.

SPECIAL TEST EQUIPMENT

The Navy has designed and issued to its maintenance activities various types of special test equipment. This was done to permit the maintenance activity to efficiently maintain the aviation fire control equipment in a minimum of time. These special test units normally contain a number of the general-purpose test instruments discussed previously.

The instrument and the equipment under test are interconnected with special cables, switches, and relays to permit monitoring of various circuits within the equipment. Means are also provided for the injection of test signals (which may be calibrated in amplitude, phase, or frequency), simulating the operation of the equipment in flight conditions. In some special test equipments, a calibrated standard for comparison with the equipment's output is also provided, thus providing a go no-go indication.

A discussion of the types and theory of operation of the various special test equipments is beyond the scope of this course. However, it is suggested that the technicians utilizing special test equipments avail themselves of the *Handbooks of Operating Instructions* for serious study.

QUIZ

1. A multimeter having a low sensitivity could be used
   - a. for quick rough readings where approximations are adequate
   - b. where a high degree of accuracy is required
   - c. to check the accuracy of a bridge circuit
   - d. to measure low voltage in a high impedance circuit
2. Most a-c voltmeters are calibrated to indicate __________ voltage.
   - a. average
   - b. peak-to-peak
   - c. peak
   - d. effective
3. A d-c bridge is used for precision measurements of
   - a. inductance
   - b. capacitance
   - c. resistance
   - d. impedance
4. To observe two complete cycles of the input waveform on an oscilloscope, the sweep frequency must be _______________ the input frequency.
   - a. equal
   - b. one-half
   - c. twice
   - d. one-fourth
5. Lissajous figures are used primarily to make ________ comparisons.
   - a. frequency
   - b. voltage
   - c. current
   - d. impedance
6. Two signals of the same frequency and amplitude, but 90° out of phase, applied to the vertical and horizontal plates of an oscilloscope will produce a/an
   - a. vertical line
   - b. ellipse
   - c. horizontal line
   - d. circle

7. Wavemeters are used to measure
   a. frequency
   b. current
   c. voltage
   d. resistance

8. The process by which the sweep frequency of an oscilloscope is adjusted to that of the observed waveform is called
   a. alinement
   b. balancing
   c. calibration
   d. synchronization

9. When using the OS–26/USM–24 to observe a particular portion of the trace, the sweep is
   a. externally triggered
   b. delayed
   c. compressed
   d. intensity modulated

10. When measuring d-c voltages, the most accurate reading is obtained by selecting the range that will give a ____________ reading.
    a. midscale
    b. low scale
    c. high scale
    d. high or low scale

11. One source of error in a meter reading is the use of the meter in a strong magnetic field. In many cases the error will remain after the meter is removed from the magnetic field. This is usually caused by
    a. magnetizing the meter armature
    b. permanently magnetizing the case of the batteries
    c. reversing the polarity of the meter movement
    d. magnetizing the meter field coil

12. What is the main factor that influences the accuracy of an a-c meter as the frequency of the voltage to be checked increases?
    a. Field core hysteresis losses
    b. Temperature variations
    c. Increasing impedance of the meter rectifier
    d. Shunt capacity within the meter

13. When using a "bridge" to measure resistance, what is the value of R_x if $R_1 = 80$ ohms, $R_2 = 120$ ohms, and $R_3 = 280$ ohms?
    a. 420 ohms
    b. 400 ohms
    c. 42 ohms
    d. 4,200 ohms

14. What is the ratio of frequencies applied to the H and V inputs if the display of the oscilloscope is a figure eight (8)?

    a. 2 to 3
    b. 1 to 4
    c. 1 to 1
    d. 2 to 1

15. To obtain an accurately calibrated output from a signal generator, the generator

    a. output meter must read at midscale
    b. dummy load must be used at all times
    c. must be working into its rated load
    d. frequency control must be at mid-position

16. Using a 1000 Ω/v multimeter on its 15-volt range, a circuit reading of 7.5 volts is obtained. On its 30-volt range a reading of 10 volts is obtained. The true voltage is approximately

    a. 8.75
    b. 11.25
    c. 15.00
    d. 17.5

17. With reference to figure 2–6 when the bridge is balanced, the

    a. charge on C_e is minimum
    b. shadow angle is increased
    c. plate current of V_1 is reduced
    d. charge on C_e is minimum

18. The push interlock switch on the rear of the OS–26/USM–24 is used to

    a. allow external synchronization
    b. connect the vertical deflection plates to the direct input terminals
    c. prevent operation without adequate ventilation
    d. disconnect the blower motor

19. Assume that a direct probe (no attenuation) is being used with the OS–26/USM–24. The V MULTIPLIER is set on 300. The vertical gain control is adjusted to give the same vertical deflection as the CAL volts position which reads 0.8. What is the r.m.s value of the input signal?

    a. 85
    b. 120
    c. 240
    d. 375

20. Using the OS–26/USM–24, it is desired to view a pulse having a repetition rate of 1,000 c.p.s. The SWEEP MICROSECOND and FINE SWEEP would then be adjusted so that the total time of the horizontal sweep would be approximately
    a. 1,000 microseconds
    b. 500 microseconds
    c. 750 microseconds
    d. 250 microseconds

21. The output meter of the Audio Oscillator TS–382B/U monitors the output
    a. frequency
    b. current
    c. impedance
    d. voltage

22. To observe more than one cycle of a waveform on an oscilloscope, the sweep frequency must be adjusted until the input frequency is
    a. lower than the sweep frequency
    b. equal to the sweep frequency
    c. a multiple of the sweep frequency
    d. triggering the sweep generator

23. A heterodyne frequency meter may be used as a signal generator and as a/an
    a. absorption meter
    b. sweep generator
    c. wavemeter
    d. impedance meter

24. To check the fundamental frequency of the crystal-controlled oscillator in a heterodyne frequency meter
    a. another marker generator should be used
    b. comparison against WWV transmissions should be made
    c. the variable oscillator may be used to beat with the crystal oscillator
    d. a resonant cavity with a high Q should be employed

25. Visual alinement is a technique using an oscilloscope and a/an
    a. VTVM
    b. RF signal generator
    c. FM generator
    d. marker generator

26. The audio signal generator might be used to measure the gain of a/an
    a. IF strip
    b. RF amplifier
    c. servo amplifier
    d. microwave generator

CHAPTER 3

ELECTRONIC MAINTENANCE

Electronic maintenance of aviation fire control systems may be divided into two main categories for discussion purposes. The first category is comprised of the maintenance performed on the equipment while it is installed in an aircraft located either on the line or in the hangar, and that maintenance performed on the aircraft resulting from changes and/or modification of the fire control equipment. This category will be called LINE MAINTENANCE. The second category is comprised of the maintenance performed on the equipment that has been removed from the aircraft and taken to the shop for checking or repair. This category will be called SHOP MAINTENANCE. To maintain aviation fire control systems in dependable operating condition requires effective electronic maintenance on both the line and in the shop. They are equal in importance and both categories shall be discussed in this chapter.

LINE MAINTENANCE

Line maintenance, as previously mentioned, is the maintenance performed on aviation fire control equipment while installed in the aircraft. It will usually consist of performance checks, periodic aircraft maintenance inspections, aircraft armament changes, and troubleshooting.

The performance checks, usually directed by local authority, serve to detect malfunctions or erratic operation of the equipment prior to the preflight inspection conducted by the pilot or bombardier. The performance checks held by the line maintenance crew will greatly reduce the "gripes" resulting from preflights, thus saving the aircraft from a delayed or aborted mission.

Aircraft Maintenance Inspections

The aircraft maintenance inspections, specified by the Bureau of Aeronautics to be accomplished at certain intervals of time or on specific occasions, are prepared for each type and model of naval aircraft, and shall be conducted as directed by the inspection forms. These inspections make it possible to keep an accurate account of aviation fire control equipment's operation time, and provide a complete check of the fire control system's performance. They also provide a check on the condition of the various cables, clamps, connectors, mounts, seals, and other equipment and accessories associated with the fire control equipment. The type of inspection will govern to what extent and which items are to be checked. The following aircraft maintenance inspections are briefly stated as to type and general requirements.

DAILY.—This inspection will be accomplished between the last flight of the day and the next scheduled flight. It replaces the postflight inspection called for in earlier inspection handbooks. This inspection is basically a combination of requirements for checking equipment that requires daily verification of satisfactory functioning, plus requirements that prescribe searching for defects that become apparent after the aircraft has been flown. It is intended that evidence of cable chafing, loose equipment, and similar conditions be discovered and corrected during this inspection to preclude progression of such relatively minor problems to a state that would require major maintenance to remedy the deficiency. The inspection is therefore an important daily function that should be performed with care.

PREFLIGHT.—This inspection will be accomplished immediately prior to each flight by flight personnel. It consists of checking the aircraft for flight preparedness by performing visual examinations and operational tests to discover defects and maladjustments that, if not corrected, could cause accidents or aborted missions.

INTERMEDIATE.—The intermediate inspection is basically a limited overall examination of the condition of the aircraft and all equipment installed therein. The inspection includes certain requirements that are also applicable to the daily or preflight inspections, and that must be performed more frequently than the major inspections. The statement of each requirement, as indicated on the inspection form, indicates how thorough the inspection or test should be. Intermediate inspections will normally be accomplished at the following intervals:

1. The first intermediate inspection will become due at the expiration of 60 flying hours, plus or minus 6 hours, after the preceding major inspection.
2. The second intermediate inspection will become due at the expiration of 60 flying hours, plus or minus 6 hours, after the first intermediate inspection.
3. The third intermediate inspection will become due at the expiration of 60 flying hours, plus or minus 6 hours, after the second intermediate inspection.

MAJOR.—The major inspection is a thorough and searching inspection of the entire aircraft and its equipment. The inspection includes certain requirements that are also applicable to the daily, preflight, and intermediate inspections. The statement of each requirement, as indicated on the inspection forms, indicates how thorough the examination or inspection should be.

The major inspection will be accomplished at the expiration of 60 flying hours, plus or minus 6 hours, after the third intermediate inspection following the preceding major inspection. This is normally 240 flying hours after the preceding major inspection.

OTHER NAME INSPECTION.—The daily, preflight, intermediate, and major check sheets contain, for the most part, all essential maintenance inspections required to be accomplished on the "LINE" and during periodic "HANGAR" checks, and at an interval compatible with current maintenance experience. All or any portion of these check sheets may be utilized for other supplemental local "name" inspections.

If, during an inspection or performance check, it is determined that a unit, assembly, or subassembly must be removed for repair or replacement, the technician must insure that all steps are taken during replacement for proper system operation. That is, he must check to see that all cables are properly connected, all mountings are safety wired, etc. These items are not normally found on the various check lists.

Preparation for Inspection

Detailed preparations for inspections are not covered in the *Handbook of Inspection Requirements* or by the check sheets. Users of the check sheets are expected to be familiar with items, such as controls, switches, and the necessary workstands, ladders, tools, auxiliary power, etc., required. Ground handling equipment and special tools are described and listed in the aircraft's *Handbook of Maintenance Instructions* and *Illustrated Parts Breakdown.* The line maintenance crew for the aviation fire control division should be thoroughly familiar with the information and safety precautions contained in these publications before inspecting the aircraft.

Inspection Check Sheets

Inspection check sheets are prepared by the Bureau of Aeronautics for each type of aircraft. One check sheet is provided for use with either the daily or preflight inspection and one is provided for use with either the intermediate or major inspection.

The daily and preflight inspection sheet, a portion of which is shown in figure 3–1, contains seven columns as follows:

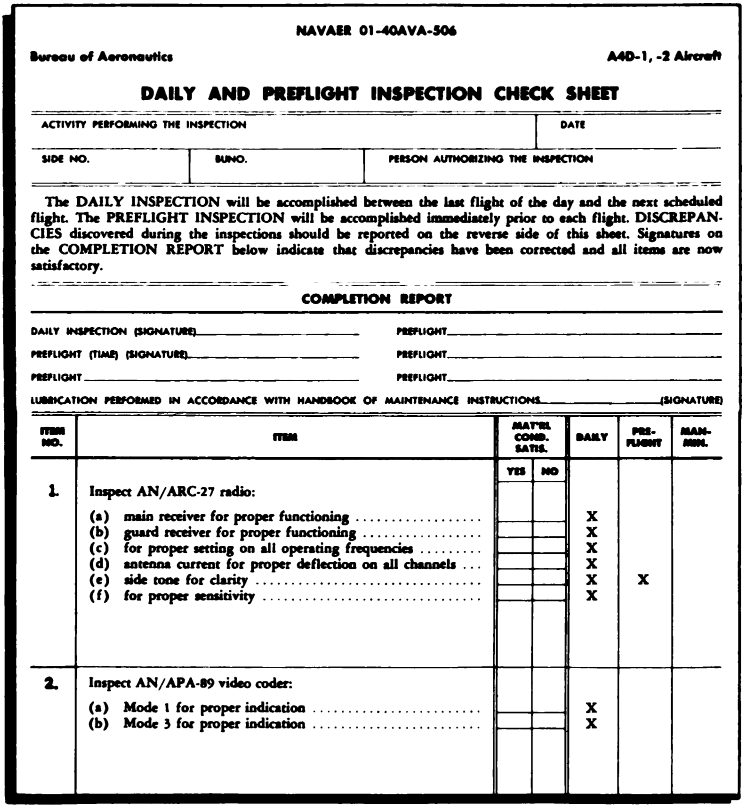
Column 1. Item number on the inspection.
Column 2. Item to be checked.
Columns 3 and 4. Material Condition Satisfactory, YES or NO.

Column 5. Daily—items that must be performed on daily inspection will have an X opposite them in this column.

Column 6. Preflight—items that must be performed on preflight inspection will have an X opposite them in this column.

Column 7. Man–Min.—the number of man minutes required to perform the inspection is filled in opposite each item.

The inspection sheet also contains a section entitled "Completion Report" that must also be completed by the



NAVAER 01-40AVA-506

Bureau of Aeronautics **A4D-1, -2 Aircraft**

DAILY AND PREFLIGHT INSPECTION CHECK SHEET

ACTIVITY PERFORMING THE INSPECTION | DATE

SIDE NO. | BUNO. | PERSON AUTHORIZING THE INSPECTION

The DAILY INSPECTION will be accomplished between the last flight of the day and the next scheduled flight. The PREFLIGHT INSPECTION will be accomplished immediately prior to each flight. DISCREPANCIES discovered during the inspections should be reported on the reverse side of this sheet. Signatures on the COMPLETION REPORT below indicate that discrepancies have been corrected and all items are now satisfactory.

COMPLETION REPORT

DAILY INSPECTION (SIGNATURE)__________ PREFLIGHT__________

PREFLIGHT (TIME) (SIGNATURE)__________ PREFLIGHT__________

PREFLIGHT__________ PREFLIGHT__________

LUBRICATION PERFORMED IN ACCORDANCE WITH HANDBOOK OF MAINTENANCE INSTRUCTIONS__________(SIGNATURE)

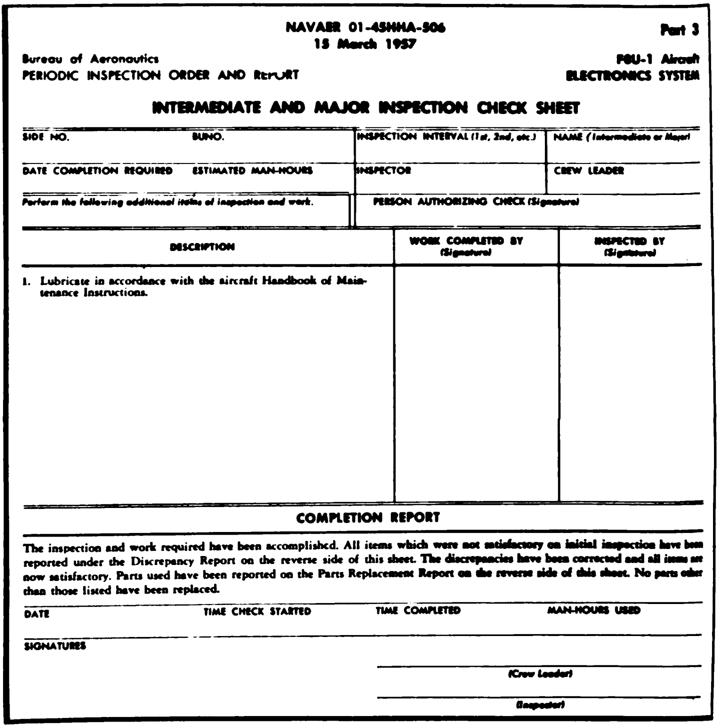
ITEM NO.	ITEM	MAT'RL COND. SATIS.		DAILY	PRE-FLIGHT	MAN-MIN.
		YES	NO			
1.	Inspect AN/ARC-27 radio:					
	(a) main receiver for proper functioning			X		
	(b) guard receiver for proper functioning			X		
	(c) for proper setting on all operating frequencies			X		
	(d) antenna current for proper deflection on all channels			X		
	(e) side tone for clarity			X	X	
	(f) for proper sensitivity			X		
2.	Inspect AN/APA-89 video coder:					
	(a) Mode 1 for proper indication			X		
	(b) Mode 3 for proper indication			X		

Figure 3–1.—Daily and Preflight Inspection Check Sheet.

person or persons performing the inspection. This section is located on the first page of the form as shown in figure 3–1.

The intermediate and major inspection check sheet is divided into sections comprising the various systems within the aircraft. Typical divisions of the check sheet may be: airframes system, landing gear system, utility system, power plant system, fuel system, armament system, fire control system, bomb director system, and electronics system. However, all aircraft are not divided into the same systems, and in some cases the fire control equipment may be contained in the electronics system.

The listing of items to be checked is similar to the Daily



NAVAER 01-45HHA-506
15 March 1957

Part 3

Bureau of Aeronautics
PERIODIC INSPECTION ORDER AND REPORT

F8U-1 Aircraft
ELECTRONICS SYSTEM

INTERMEDIATE AND MAJOR INSPECTION CHECK SHEET

SIDE NO.
BUNO.
INSPECTION INTERVAL (1st, 2nd, etc.)
NAME (Intermediate or Major)
DATE COMPLETION REQUIRED
ESTIMATED MAN-HOURS
INSPECTOR
CREW LEADER
Perform the following additional items of inspection and work.
PERSON AUTHORIZING CHECK (*Signature*)

DESCRIPTION	WORK COMPLETED BY (*Signature*)	INSPECTED BY (*Signature*)
1. Lubricate in accordance with the aircraft Handbook of Maintenance Instructions.		

COMPLETION REPORT

The inspection and work required have been accomplished. All items which were not satisfactory on initial inspection have been reported under the Discrepancy Report on the reverse side of this sheet. The discrepancies have been corrected and all items are now satisfactory. Parts used have been reported on the Parts Replacement Report on the reverse side of this sheet. No parts other than those listed have been replaced.

DATE
TIME CHECK STARTED
TIME COMPLETED
MAN-HOURS USED

SIGNATURES

(*Crew Leader*)

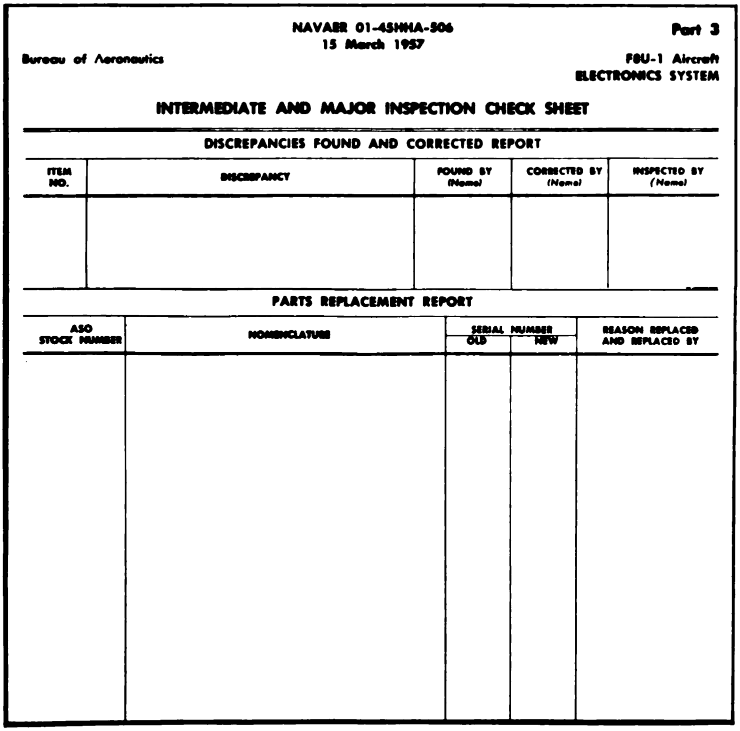
(*Inspector*)

(A)

Figure 3–2.—(A) Periodic Inspection Order and Report and Completion Report.

and Preflight Inspection Check Sheet with the exception of the headings on columns 5 and 6, which are entitled "Intermediate Inspection" and "Major Inspection," respectively. In addition to the listing of items to be checked, the check sheet for each system includes a PERIODIC INSPECTION ORDER AND REPORT, COMPLETION REPORT, DISCREPANCIES FOUND AND CORRECTED REPORT, and PARTS REPLACEMENT REPORT. (See fig. 3–2 (A) and (B).)

The Periodic Inspection Order and Report is partly filled in by the maintenance officer before issuing it to a division for a periodic inspection. He will list additional work which is to be performed during the periodic in-



NAVAER 01-45HHA-506
15 March 1957

Part 3

Bureau of Aeronautics

F8U-1 Aircraft
ELECTRONICS SYSTEM

INTERMEDIATE AND MAJOR INSPECTION CHECK SHEET

DISCREPANCIES FOUND AND CORRECTED REPORT

ITEM NO.	DISCREPANCY	FOUND BY (Name)	CORRECTED BY (Name)	INSPECTED BY (Name)

PARTS REPLACEMENT REPORT

ASO STOCK NUMBER	NOMENCLATURE	SERIAL NUMBER		REASON REPLACED AND REPLACED BY
		OLD	NEW	

(B)

Figure 3–2.—(B) Discrepancies Found and Corrected Report and Parts Replacement Report.

spection interval. Examples of additional work are: (1) flight discrepancies, (2) squadron work orders, (3) incorporation of changes or bulletins, etc. Items noted in the "Work Completed by" column on this form will be signed off by the person completing the work, not necessarily a member of the inspection crew.

The Discrepancies Found and Corrected Report is used to indicate to the Maintenance Officer what discrepancies were found, who discovered the discrepancies, and who accomplished the necessary work.

The Parts Replacement Report shall indicate every part that is replaced during the inspection interval. (NOTE: A PART is defined as a piece, or two or more pieces joined together, which is an element of a subassambly, an assembly, or unit, and is of such construction that it is normally not subjected to further disassembly for maintenance purposes—electron tubes, resistors, transformers, potentiometer, tube socket, etc.).

The responsibility for the completeness of the inspection rests with the "crew leader." The crew leader is the person in charge of and responsible for the proper performance of the inspection for a particular system. His signature certifies that all items of that system have been properly inspected and reported.

Aircraft Armament Changes

Aircraft Armament Changes as described in *Aviation Fire Control Technician 3*, NavPers 10388, chapter 14, consist of mandatory changes or modifications to specific items of armament equipment. However, some of these changes require that additional cables, clamps, and other modifications either be installed or changed in the aircraft. This maintenance will normally be the responsibility of the line crew. Detailed information on how and when the change is to be incorporated, what equipment is affected, and estimated man-hours required for the change is normally contained in the directive which will be classified either as

ROUTINE, URGENT, or IMMEDIATE action depending on the nature of the change.

ROUTINE action changes are normally accomplished at the discretion of the maintenance activity, but should be accomplished at the earliest opportunity.

URGENT action changes shall normally be accomplished in all applicable equipment not later than the next periodic check period. This usually includes equipment in storage as well as that in use.

IMMEDIATE action changes shall be accomplished in all applicable equipment prior to further use and immediately upon availability of material.

Urgent action and immediate action armament changes are readily identified by the words URGENT ACTION or IMMEDIATE ACTION printed in red on the first or cover page of the change. It also contains a red border to signify its importance.

Aircraft Log Book

The Chief of the Bureau of Aeronautics is vitally interested in improving the aircraft maintenance program of which aircraft logs and records are an integral part. He strongly recommends that maintenance activities wage a vigorous campaign to insure that these important records are maintained at the highest possible standard. In this regard, it is essential that personnel assigned to the preparation and maintenance of logs and records be thoroughly competent, properly trained, and familiar with the technical language pertaining to inspections, modifications, and maintenance of naval aircraft.

It is of particular importance that these records be initiated correctly. Proper maintenance of aircraft and component logs and records cannot be overemphasized. Incorrect records serve to confuse; and when used as a guide, frequently result in many hours of corrective work. Even more serious is the fact that the integrity of the entire aircraft is questionable when records do not reflect the incorporation of changes, inspections, and other important maintenance data.

The following log books, established by the Bureau of Aeronautics, are of particular interest to the Aviation Fire Control Technician:

1. *Aircraft Log Book.*
2. *Aircraft Inventory Record/Standard Inventory Log.*
3. *Handbook of Weight and Balance Data.*

AIRCRAFT LOG BOOK.—The *Aircraft Log Book* currently in use is a hard cover, looseleaf type containing separators and insert pages. It contains general instructions for entries of transfers, overhauls, repairs, changes, and bulletins affecting the aircraft. The log is maintained by the aircraft maintenance office of the station or activity to which the aircraft is assigned. Therefore, it is of utmost importance that any and all maintenance performed on an aircraft be reported in detail by the line maintenance crew to the aircraft maintenance office.

AIRCRAFT INVENTORY RECORD/STANDARD INVENTORY LOG.—The *Aircraft Inventory Record* and the *Standard Inventory Log* provide for the listing of all aircraft inventory items and shortages thereto. Both documents also provide for certification of the aircraft inventory and a record of transfers, and are used as the instrument of transfer as well as the basis for the inventory which is required for each change of custody. No aircraft will be transferred or accepted without an inventory record or log. All inventory records and logs, though performed by the line maintenance crew, shall be maintained in the aircraft maintenance office of the unit or activity having custody of the aircraft.

The *Standard Aircraft Inventory Log* is discussed further in chapter 13, "Material and Spare Parts."

HANDBOOK OF WEIGHT AND BALANCE DATA.—The *Handbook of Weight and Balance Data* provides a standard system for weight and balance control by field activities. The forms, charts, and records in this handbook are initiated by the factory prior to delivery of the aircraft to the Navy, and provide the means of maintaining a continuous and current record of the basic weight and balance information during the aircraft's service life. The data recorded in this handbook permits determination of takeoff, flight, and landing conditions, and checks for conformance with weight and center of gravity restrictions for flight clearance. Procedures and instructions for maintaining the weight and balance records are contained in the handbook. These records shall be maintained by operating and overhaul activities to reflect the effect of changes in operating equipment inventory and incorporation of service changes. The handbook shall be retained in the aircraft at all times, and is to be aboard at the time of transfer of the aircraft.

The aircraft logs discussed are a sample of the many aircraft logs that must be maintained by the aircraft maintenance office of an activity. These logs can be kept current and accurate if the maintenance office is informed of all maintenance performed on the aircraft. The accurate and timely relay of this information by the various line maintenance divisions will greatly reduce the workload on the maintenance office, and result in better overall maintenance control.

Troubleshooting

Troubleshooting performed by a line maintenance crew consists mainly of isolating and correcting malfunctions which are found during the performance checks, periodic aircraft inspections, or during the checking of "gripes" after a flight. Some troubles may be rather simple and obvious, while others may be complex and time consuming. The line maintenance technician will find through experience that the more familiar he becomes with his equipment the simpler his troubles will seem. Although experience and familiarity with the equipment are necessary, the technician must also use a systematic logical approach for the isolation of troubles.

The process of component isolation by logical reasoning and thought will eliminate unnecessary switching of equipment components and, thus, a saving of both time and labor. The technician should logically analyze the information he has at hand, such as the indications obtained from a performance check, or the information contained on a "gripe" sheet from the operator, and eliminate, by logical reasoning, many of the system's units as a possible source of trouble. He may often isolate the trouble to a particular unit, allowing replacement of one unit instead of haphazardly exchanging units in hopes of finding the trouble.

However, if the trouble does not resolve itself from a logical solution of the available data, the technician must then utilize the various aids available to him. The wiring diagrams, functional drawings, and troubleshooting information contained in the *Handbook of Service Instructions* for the defective equipment should be fully utilized. This information should be especially useful in checking power distribution and signal flow through the different components of the system. Voltage and resistance charts should also be a great aid when isolating a trouble to a particular part or subassembly.

Signal Tracing

Signal tracing is another aid to troubleshooting often used by a line maintenance crew. It consists of tracing a signal from its source through the system, or until a faulty indication is obtained.

Signal tracing requires a comparison of signals observed in the equipment with those shown in the *Handbook of Service Instructions.* However, the use of indicating test instruments is required.

The maintenance publications are used to obtain information on the cable numbers, pin numbers in connectors, and location of bulkhead connectors and terminal boards. The indicating test instruments are used to measure or indicate the presence of a signal at the various check points. These test instruments may be visual indicating devices, such as a multimeter; or audio devices, such as earphones. The signal is traced from the source until it is lost at some check point. If this point is the output of a unit, replace the unit and recheck. If the signal is lost at some other point, check the cables, connectors, or terminal boards from the point of test back toward the source to the last good check point. This latter check is usually a continuity check with power off as discussed in the Navy Training Course, *Aviation Fire Control Technician 3*, NavPers 10388, chapter 10.

As stated previously, these are but a few of the aids to efficient line troubleshooting. Your ability to troubleshoot will depend on your proficiency to utilize the tools and information at your command.

Final Checks

It is necessary to make a final check of the equipment's performance and the aircraft's security after each periodic aircraft inspection, performance check, and performance of corrective maintenance. This final check serves to evaluate the overall system performance, to insure dependable operation during flight, and to check the flight readiness of the aircraft itself.

The system performance check, as discussed previously, is a complete check of the system's performance in all modes of operation. It usually consists of inserting several problems into the system, and then checking their solution by the equipment against predetermined values. These problems are normally of such a nature that the entire system will have to function correctly to produce the desired result. Some of these problems require the use of special test equipment to either insert certain values or monitor the results, depending on the type of system employed.

The final check on the aircraft's security consists of a complete and thorough inspection of all the equipment mounts and racks, and the replacement of all inspection panels, plates, and other equipment removed from the aircraft during the inspection or while performing maintenance. This includes the use of safety wire, stop nuts, and other means for securing equipment in the aircraft where needed. The final checks also include the removal of workstands, ladders, power vehicles, and other equipment from the line or hangar. The last, but one of the most important checks to make, is the condition of the ramp or working area. Make sure all loose material such as nuts, bolts, washers, bits of safety wire, and other articles which may have dropped on the ramp or in the hangar are picked up and disposed of, or returned to the line shop. It takes only a small piece of "junk" sucked into a modern jet engine seconds to make junk out of the entire engine. Do not let your carelessness cost extra man-hours and money to your activity. One second spent picking up a loose nut may save hours of maintenance replacing an engine and an untold amount of money.

SHOP MAINTENANCE

Shop maintenance as it concerns the AQ is the maintenance performed on aviation fire control equipment while it is removed from the aircraft and is in the maintenance shop for check and/or repair. The purpose of shop maintenance is to perform both preventive and corrective maintenance on fire control equipment and units thereof.

Work Flow

The efficient operation of a maintenance shop is based primarily on the organization of the shop equipment, personnel, and a systematic procedure for planning the work assignments and controlling the flow of equipments to be repaired within the shop. The first two items are performed by the senior chief petty officers and shall not be discussed in this course. However, the procedures used in the control of work through the shop is of vital interest to the AQ2.

The system normally used by aviation fire control maintenance shops to control the equipment flow and work performed makes use of colored tags, location logs, and equipment work logs.

The colored tags are used to denote the condition of the unit, suspected trouble, serial number, and status. These tags are generally of three colors—green, yellow, and red. The color of the tag used denotes status only. The green tag is used to denote that the equipment has been completely checked, alined, and ready for use. The yellow tag is used to denote that the equipment needs maintenance of some form. For example, an equipment that has been removed from an aircraft system due to failure or malfunction, or a new piece of equipment which requires an acceptance check or alinement before it is ready for use, will be marked with a yellow tag.

The red tag is used to denote that the equipment is to be turned in to a higher maintenance activity for overhaul since the trouble is beyond the scope of the local repair activity. It is also used when the equipment has been designated as not to be repaired by a field activity.

The location logs serve to accurately account for all serialized components. These logs are of utmost importance, and their accuracy and completeness are the responsibility of every man in the division. They prove of untold value in inventory reporting, survey requests, and many other functions which are necessary for proper shop maintenance.

The location logs should list each serialized component or subcomponent in the custody of the activity, and their exact location, such as the serial number of the aircraft in which it is installed, shop spaces, line maintenance spaces, or storeroom. In the case of a serialized subcomponent, the serial number of the major component in which it is installed should also be recorded. The location logs should have a space under each item for entering the date on which an item is moved. It should also include space for remarks which show disposition of material in case of turn in or transfer to another activity.

The equipment work logs are used to keep a record of all maintenance work performed on a piece of equipment.

These logs should also include the unit serial number and should be kept up to date by the technician performing the maintenance. The equipment work logs provide a ready reference to the total work performed on any component, and indicates if any particular component is causing an undue amount of trouble. They are exceptionally useful in correcting recurring troubles as they should contain information on all parts repaired or replaced.

The methods discussed are but a few of the many required to govern and control shop maintenance. Each activity may have its own procedures, but all will use some portion or variant of the methods discussed in the previous paragraphs to control work flow in the aviation fire control maintenance shops.

Preventive Maintenance

Maintenance performed in an aviation fire control shop to prevent the likelihood of future troubles or malfunctions is usually referred to as preventive maintenance. This form of maintenance consists mainly of visual checks of the equipment prior to and during operation, cleaning the equipment and the various components therein, lubricating, and the periodic inspections as discussed under line maintenance.

Visual checks.—The visual checks consist of visually checking the equipment for loose leads, proper connections, leaking capacitors, etc., prior to applying power to the equipment. This applies particularly to new equipment, equipment returned from overhaul, equipment which has been preserved or stored for long periods of time, and equipment which has been exposed to the elements (sun, rain, high humidity, etc.). A close visual inspection should also be conducted on O-rings, gaskets, and other type seals when the equipment under check is a pressurized component. This visual inspection will often reveal discrepancies that may be corrected at that time with a minimum amount of labor and parts. Such discrepancies, if left uncorrected, might result in a major maintenance problem.

CLEANING.—Cleaning the equipment and the various components consists of removing dust, grease, and other foreign matter from the covers, chassis, and operating parts. This includes the removal of corrosion, fungus, and all other types of matter which could cause operating failure of the equipment. The methods used to clean the various parts and units will vary, but usually a vacuum cleaner is used to remove the loose dust and foreign matter. The remainder is then wiped or removed with a clean lint-free cloth. If it is necessary to remove grease or other petroleum deposits, the cloth may be moistened with alcohol or dry-cleaning solvent. After removing the grease, the part should be wiped dry, or allowed to dry by evaporation prior to applying power. To remove corrosion, fine grit sandpaper may be used. However, a vacuum cleaner should be used while sanding to remove the residue and prevent it from falling into the equipment.

Lubrication

Lubrication of electronic equipment consists mainly of lubricating the mechanical parts which are associated with the electronic equipment. This applies mainly to the mechanical and electromechanical computers of the fire control system. This procedure is discussed in the chapters dealing with computers, and will not be discussed at this time. However, other items of equipment which may need periodic lubrication such as unsealed bearings, antenna rotating joints, waveguide rotating joints, etc., should be lubricated as directed by the equipment's *Handbook of Service Instructions.* The type of specification number of a lubricant should be strictly followed as the viscosity of a lubricant will change with a change in operating temperature. High operating temperatures cause lubricants to become thin, while low operating temperatures cause lubricants to thicken or harden. Therefore, the lubricant used for a particular job will depend on the operating characteristics and temperature at which operated. Particular attention should be paid to equipment lubrication where the aircraft is flown at high altitudes. A special lubricant should be used which will not harden and bind the rotating joints, thus preventing an overload on the drive motors, shafts, and electrical circuits involved.

Corrective Maintenance

When defective parts or unsatisfactory operation have been revealed in any of the inspections, it is necessary to analyze the equipment, find the defective part or parts, and make the appropriate replacement or repair. In general, the most effective procedure for this analysis consists of first isolating the stage containing the defect and then locating the particular part at fault by careful measurements within the stage.

The general methods which are used in locating defective electronic stages and parts can be listed as follows:

1. Preliminary visual and operating checks.
2. Voltage measurements.
3. Resistance measurements.
4. Current measurements.
5. Signal tracing methods.

The first logical step after the defective unit has been installed in the bench test system is a visual check of the unit. It should be thoroughly inspected for broken leads, parts that are burned, loose mountings, and any other indications of failure. If no defects are found, power should be applied to the equipment and the unit should be observed for any overheating or smoking.

In the preliminary check, the experience of the technician is an important factor, and the knowledge gained from previous difficulties with the equipment often serves as a guide in knowing what to expect. Both the experienced and the inexperienced technician can find assistance in preliminary checking by consulting the *Handbook of Service Instructions* for the specific equipment involved, since these handbooks often give detailed procedure for making the initial inspections. However, many electronic faults do not result in symptoms which can be detected visibly or audibly, and it is frequently necessary to resort to other methods of detecting part failure.

Voltage measurements, which are often used to find defective parts, are made at various points in the stage suspected of being at fault. The observed voltage values are then compared with the normal voltage values given in the *Handbook of Service Instructions;* and from this comparison, the defect can often be isolated. Voltage checks are most effective when applied within a single stage and after previous checks have been made to partially localize the defect. This is true because modern electronic equipment is complex, and a great deal of time is required to check all the voltages present in all the stages.

Resistance measurements are used in a manner similar to voltage measurements except that the equipment is switched off and resistance values are measured with an ohmmeter. The resistance values are then compared with the normal values given in the maintenance publications. This method, like voltage measurements, is most effectively used after the trouble has been isolated to a particular stage since reliance on resistance measurement alone is too time consuming to be efficient. After the trouble has been isolated, the ohmmeter is a very useful instrument and often leads the technician to the trouble quickly.

A typical example of a routine resistance check applied to a single part is the ohmmeter method of checking electrolytic capacitors. A resistance measurement is made on the discharged capacitors, using the high-resistance range of the ohmmeter. When the ohmmeter leads are first applied across the capacitor, the meter pointer rises quickly and then drops back to indicate a high resistance. The test leads are then reversed and reapplied. The meter pointer should rise again—even higher than before—and again drop to a high value of resistance. The deflections of the meter are caused when the capacitor is charged by the battery of the ohmmeter. When the leads are reversed, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

If the capacitor is open-circuited, no deflection will be noted. If the capacitor is short-circuited, the ohmmeter indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the fact that leakage is present between the electrodes. A typical set of values is 50,000 ohms in one connection and 500,000 ohms in the reversed polarity of the meter. The difference in resistance results because the capacitor is a polarized device.

Current measurements may also be made in various circuits of the equipment to detect the presence of abnormal current values. After the circuits have been measured, the readings are compared with the normal values given in the maintenance notes.

Signal tracing is a very effective method of locating defective stages in many types of electronic equipment. It is especially useful when servicing amplifiers and other equipment which normally contain no built-in meters. In signal tracing, a signal voltage similar to that which is normally present in the operation of the stage is taken from a signal generator and is then applied to the input terminals of the circuit in question. The signals which result from this application are then checked at various points in the device, using test instruments such as vacuum tube voltmeters, oscilloscopes, output meters, or any type high-impedance instrument which is appropriate.

By signal tracing methods, the gain or loss of amplifiers can be measured; and the points or origin of distortion, oscillation, or any abnormal effect can be localized.

The gain measurement can be used as an example of an important method in signal tracing. By this procedure, a defective stage can be found quickly in a servo amplifier. A signal generator with the output attenuator calibrated in microvolts and an output meter are used. It is helpful to have data concerning the normal gain of the various stages of the device.

The output meter is connected across the amplifier's output. The output of the signal generator is applied to the grid circuit, or input terminals, of one of the amplifiers.

The attenuator of the signal generator is then adjusted until the output meter reads an appropriate value which will serve as a reference figure. The output of the signal generator is then applied to the input of the stage under test, and the attenuator is adjusted until the reference value again is registered on the output meter. The gain of the stage is found by dividing the second value of the signal (taken from the calibrated attenuator) by the value of the signal applied to the input of the stage.

As an example, suppose the signal generator delivers a voltage of 400 microvolts to the grid of an amplifier to cause the output meter to indicate the reference value. When the generator signal is applied to the following grid, the signal strength must be increased to 4,000 microvolts to cause the output meter to indicate the reference value. The gain of the stage is $\frac{4{,}000}{400}$ or 10.

If similar measurements made in the remaining stages of the circuit reveal one in which the gain is lower than normal or is zero, that stage can then be thoroughly checked by voltage measurement of parts until the defective one is found.

One of the most frequent sources of trouble in electronic equipment is failure of vacuum tubes. It would seem from this that the first step in electronic maintenance should be the testing of all such tubes in a tube tester. While tube testers fill a useful and necessary place in electronic maintenance, it should be remembered that these instruments have certain limitations. The leading objection is that testers do not necessarily test the tube under operating conditions.

Tube testers are of two general types: emission tester and mutual conductance tester. In the emission tester, the filament and cathode of the tube are heated, and fixed voltages are applied to the tube electrodes. The resulting tube current is then measured to determine the amount of emission present. The test is based on the fact that as a tube ages, the amount of emission from the cathode usually decreases.

In the mutual conductance tester, the changes in plate current resulting from small changes in grid voltage are measured. The test of the tube in the mutual conductance tester comes much closer to simulating circuit operation and therefore provides more accurate data on which to predict the tube's performance within a circuit. However, in the mutual conductance tester, it frequently happens that the tube condition is indicated as good when the performance of the tube under actual working conditions is poor.

A better check of a doubtful receiving tube is to test it in the equipment by applying a signal from a signal generator to the questionable stage and noting the output of the amplifier on an output meter. Substitution of a tube known to be good is then made and the resulting output is compared with the former value. The methods discussed above are very general and apply to the maintenance of almost any type of electronic equipment.

For a complete discussion on testing of electron tubes in aircraft electronic and aviation fire control equipment refer to *BuAer Electronics Material Bulletin No. 10–57*, of 30 Dec. 1957.

When a fault is known to exist in a certain stage, the following procedure is used to find the defective part:

1. Replace the tube with one of the same type that is known to be in good condition, and check to see if the trouble is corrected.

2. Measure the voltage at the tube sockets. Incorrect voltage readings indicate defective wiring or components.

3. Check the capacitors for an open or short condition. A shorted capacitor usually causes improper voltage values in the stage and may cause resistors and other components to heat excessively. An open capacitor may be located by shunting the suspected unit with a test capacitor of its same value. An open capacitor causes noise, oscillation, or absence of signal.

4. With the equipment turned off, measure the value of the fixed and variable resistors in the circuit.

5. With an ohmmeter and a schematic diagram of the circuit, check the continuity of the wiring, coils, transformers, relay contacts, and relay coils.

6. Replace any parts found defective in the above checks and operate the equipment to determine if the trouble has been completely eliminated.

Safety Precautions

The strict adherence to safety rules and regulations cannot be overemphasized. There are as many men killed or injured in accidents resulting from carelessness as are lost in combat. It is your responsibility to observe these rules, and to see that others do likewise.

General safety precautions were discussed in chapter 13, "Safety Precautions," in the Navy Training Course, *Aviation Fire Control Technician 3*, NavPers 10388.

The following safety precautions are especially applicable to line and shop maintenance and are to be observed at all times while engaged in work with or around aircraft and electrical equipment:

1. Be alert at all times.
2. Wear goggles to protect your eyes from air blasts and foreign matter.
3. Wear earplugs if exposed to jet engine noise.
4. Stay clear of props, jet intakes and exhausts.
5. Never smoke in or near aircraft or on the flight deck of an aircraft carrier.
6. Never put power on the fire control system while the plane is being refueled or taking on liquid oxygen.
7. When working around high voltage, never work alone, always keep one hand clear of the equipment, never wear rings or other conductors, and never work while wet.
8. Do not remain in front of high-powered radar antennas for long periods of time. (A radiation hazard exists if exposed for long periods of time.)

9. Always observe safety signs placed on or in the aircraft.

10. Always consult your supervisor when in doubt.

FIELD CHANGES

The changes to modernize or modify naval aircraft are distributed to the field activities by directives issued by the Bureau of Aeronautics. Typical change directives of this type are ELECTRONIC MATERIAL CHANGES, AIRCRAFT SERVICE CHANGES, AIRCRAFT ARMAMENT CHANGES, etc. Since all the change directives are similar (with the exception of the material involved) and the Aircraft Armament Changes were discussed under line maintenance, the directives proper shall not be discussed. The activity responsible for making these changes and the material kits involved shall be discussed in the following paragraphs.

Active Responsibility

The incorporation of changes as directed by the BuAer directive is normally the responsibility of the activity having custody of the aircraft on the effective date of the change directive. The effective date is assigned by the bureau when it is known that sufficient material (change kits or other parts) is available in the supply system to permit incorporation of the change. The effective date of a directive may often be the same as the issue date when no change kits or other parts are required. The effective date of a directive may be left blank when change kits or other parts are required and are unavailable at the time the change is distributed. When the required kits or parts are available, BuAer will disseminate the effective date information by message. When the required change kits or other parts are available in the supply system prior to the formal assignment of the effective date, activities concerned are authorized to requisition the required material and incorporate the change.

Responsibility for change incorporation by major operating commands and operating activities will be as follows:

1. Immediate Action changes shall be incorporated prior to further flight.

2. Urgent Action changes which have an effective date shall be incorporated not later than the next intermediate inspection, or the next major inspection. The aid of higher class maintenance activities may be utilized if necessary.

3. Routine Action changes which have an effective date are to be incorporated at the next overhaul or a special modification period.

When considered necessary, major operating commands may designate a subordinate activity to perform the change on aircraft in custody of the major command. This is usually done when the major operating command does not have adequate maintenance facilities.

Incorporation of aircraft changes while the affected aircraft are in BuAer custody (Overhaul and Repair (O&R)) will be as follows:

1. Immediate Action changes shall be incorporated prior to issue of the aircraft to an operating activity.

2. Urgent Action changes, which have an effective date of 45 days or more prior to completion of overhaul, or progressive maintenance of 60 days or more prior to delivery to the fleet custodian, shall be incorporated by O&R.

3. Routine Action changes, which have an effective date of 60 days or more prior to completion of overhaul, or progressive maintenance of 75 days or more prior to delivery to the fleet custodian, shall be incorporated by O&R.

Removal of Material

The removal of material installed in accordance with an aircraft change which has been canceled will be as follows:

1. Material installed in accordance with an aircraft change directive which subsequently is canceled shall not be removed by major operating commands unless specified within the cancellation directive.

2. If specified in the cancellation directive, the material

shall be removed during overhaul, conversion, or progressive maintenance when the disassembly process has proceeded to that degree where removal of such parts is practical and economical. Parts shall not be removed when required to maintain the structural integrity of the airframe.

3. If an aircraft change which required removal of material or equipment is subsequently canceled, reinstallation of the material removed is not required.

Field Change Kits

Field change kits are normally in the form of Aircraft Service Change Kits consisting of the necessary material and equipment to incorporate a BuAer directive change. Aircraft Service Change Kits are Code "A" Accountable items and are to be requisitioned from the primary stock point to supply the Aircraft Service Change Kits. A requisition citing the applicable aircraft's bureau number shall be submitted to the primary stock point via the local supporting supply activity. It is necessary to cite the aircraft's bureau number as kits are procured on the basis of one kit for each affected aircraft.

Change kit identification.—Change kits now on hand have been stock numbered as described below. The key to a change kit stock number asignment, for example, R82–F2H–C224, is as follows:

R82 ------- aeronautical class of material for kit of parts
F2H ------ aircraft model
C224 ------ aircraft service change number assigned

When one or more kits are required to incorporate the change in aircraft, a number 1, 2, 3, etc., shall be added after the class designation of the kit stock number to identify each different kit. When one or more kits are required to incorporate the change in spares, a capital A, B, C, etc., shall be added after the class designation of the kit stock number to identify each different kit. When the kit or kits for either aircraft or spares are those kits required to incorporate a revision to the change, a capital

A, B, C, etc., shall be added to the aircraft service change number, for example:

R82–1–F2H–C224–Kit 1 for aircraft, change 224

R82–A–F2H–C224B–Kit A for spares, change 224, revision B

R82–2–F2H–C224–Kit 2 for aircraft, change 224

The provisions of the federal cataloging program are such that the method of stock numbering herein will require change on new kits issued after conversion by ASO. Instructions pertaining thereto will be issued by ASO in time to meet the planned conversion dates.

Each change kit shipped by contractors or naval activities will be tagged with a lemon yellow tag to show the following information:

Stock Number R______________
Model______________________Airplane
Bureau of Aeronautics Service Change #____________
Contractor's Engineering Change Proposal # ECP__________________
Contract # NOA(s)____________
This kit contains items subject to age limitations—reinspect after (INSERT OVERAGE DATE WHEN APPLICABLE).

Disposition.—All change kits shall be incorporated within 60 days of the date of issue. The operating activity receiving the change kits shall advise the issuing stock point when the kit is incorporated in the aircraft (by BuNo) for which it was requisitioned. If kits received by an operating activity cannot be incorporated within 60 days from the date of issue, they shall be returned via the local supply department to the cognizant stock point.

When an aircraft is transferred from one custodian to another for which service change kits have been drawn but not incorporated, the kits shall be returned by the transferring activity to the primary stock point. The kits shall not be transferred with the aircraft. Kits being returned to the supply system shall be in all respects ready-for-issue. Since kits are procured on a one-for-one basis, no provisions can be made for broken or missing parts.

When a change is incorporated in an aircraft, the activity having custody of the aircraft shall insert in the Aircraft Log Book the date the change was installed.

Support Equipment

Support equipment consists of the special tools, jigs, fixtures, templates and other items required for the installation and/or support of aircraft service changes. All support equipment items will be stock numbered by ASO. In addition, the Aircraft Service Change Kit number will be affixed below the support equipment stock number.

Fleet activities will requisition from the primary stock point the necessary support equipment listed in the aircraft change directive under the heading SUPPORT EQUIPMENT REQUIRED. The quantity to be requisitioned will be the quantity of support equipment allowed for the specific number of changes required to be made on aircraft in custody.

Upon completion of incorporation of service changes, fleet activities will return the support equipment items to the stock point for reissue.

QUIZ

1. An aircraft has 235 hours of flight time since the last major inspection. The next inspection due is the
    a. first intermediate
    b. second intermediate
    c. third intermediate
    d. major

2. The responsibility for the completeness of an inspection rests with the
    a. maintenance officer
    b. crew leader
    c. shop chief
    d. maintenance chief

3. Equipment designated as not to be repaired by field activities is tagged with a __________ tag.
    a. red
    b. yellow
    c. green
    d. white

4. Equipment work log entries should be made by the
    a. technician performing the maintenance
    b. shop supervisor
    c. crew leader
    d. AQ shop log yeoman

5. Periodic inspections are a form of
    a. line maintenance
    b. preventive maintenance
    c. shop maintenance
    d. corrective maintenance

6. The best check of a vacuum tube can be made by
    a. an emission type tube tester
    b. a mutual conductance tube tester
    c. substitution of the suspected tube with a tube known to be good
    d. applying a signal to the questionable stage and noting the output

7. Aircraft inspection check sheets are prepared by the
    a. Bureau of Aeronautics
    b. aircraft manufacturer
    c. fleet command
    d. squadron maintenance officer

8. An aircraft armament change requiring action prior to the further use of equipment would be classified as
   a. urgent
   b. immediate
   c. routine
   d. major

9. Which of the following log books are initiated by the aircraft factory?
   a. Maintenance log
   b. Location log
   c. *Handbook of Weight and Balance Data*
   d. *Handbook of Service Instructions*

10. The final check by an Aviation Fire Control Technician on an aircraft should be
    a. a complete check of the system's performance in all modes of operation
    b. a check of the flight readiness of the aircraft and the condition of the working area
    c. the inserting of problems into the system and checking their solution against predetermined values
    d. a check of dependable operation during flight

11. Resistance measurements are most effectively used
    a. after trouble has been isolated to a particular stage
    b. as a preliminary check
    c. prior to voltage measurements
    d. with power applied to the equipment

12. When working around high voltage circuits,
    a. use only high impedance test equipment
    b. never work alone
    c. a radiation hazard exists if exposed over long periods of time
    d. work alone to avoid endangering others

13. The incorporation of aircraft changes is normally the responsibility of
    a. the supporting FASRon
    b. an overhaul and repair activity
    c. the activity having custody of the aircraft
    d. equipment contractor

14. Change kits received for an aircraft that has been transferred to another activity shall be
    a. forwarded to the activity having custody of the aircraft
    b. returned to the primary stock point
    c. held for installation in other aircraft
    d. returned to the contractor

15. All change kits shall be incorporated
    a. at the next intermediate inspection after receipt
    b. at the next major inspection after receipt
    c. within 60 days of the date of issue
    d. upon receipt

16. A change kit bearing the number R82–A–F2H–C224B indicates that the kit is
    a. aircraft, change 224
    b. aircraft, change 224, revision B
    c. spares, change 224, kit 2
    d. spares, change 224, revision B

17. Routine action changes which have an effective date of 60 days or more prior to completion of overhaul shall be incorporated by
    a. the receiving squadron
    b. a FASRon activity
    c. overhaul and repair
    d. the contractor

18. The accuracy and completeness of location logs is the responsibility of
    a. every man in the division
    b. the shop chief
    c. the log yeoman
    d. the maintenance office

19. The *Aircraft Log Book* is maintained by the
    a. engineering office
    b. line crew
    c. I & E Office
    d. maintenance office

20. Wiring diagrams, functional drawings, and troubleshooting information will be found in the *Handbook of*
    a. *Maintenance Instruction*
    b. *Service Instruction*
    c. *Weight and Balance Data*
    d. *Inspection Requirements*

21. Maintenance performed in an aviation fire control shop to prevent the likelihood of future troubles or malfunctions is usually referred to as
    a. corrective maintenance
    b. shop maintenance
    c. preventive maintenance
    d. class A maintenance

22. The first logical step after a defective unit has been installed in the bench test system is a
    - a. voltage check
    - b. resistance check
    - c. signal tracing check
    - d. visual check

23. Troubleshooting is a form of
    - a. preventive maintenance
    - b. corrective maintenance
    - c. alinement maintenance
    - d. calibration maintenance

24. Aircraft Service Change Kits are
    - a. Code "A"
    - b. Code "O"
    - c. Code "E"
    - d. Code "R"

25. When a change is incorporated in an aircraft, the activity having custody of the aircraft shall insert the date of change in the
    - a. *Aircraft Inventory Record*
    - b. *Standard Inventory Log*
    - c. *Aircraft Log Book*
    - d. *Handbook of Maintenance Instructions*

CHAPTER 4

MAGNETIC AMPLIFIERS

Electronics personnel usually associate amplification of voltage or power with vacuum and gas tubes. However, several devices accomplish amplification without the use of tubes. One of these, the MAGNETIC AMPLIFIER which has been in use here and abroad for several years, will be discussed in this chapter.

The term AMPLIFICATION, in general, refers to the process of increasing the amplitude of voltage, current, or power. The term AMPLIFICATION FACTOR is the ratio of output to input. The input is a signal that controls the amount of available power delivered to the output. Thus, tubes are really valves that permit a controlled amount of power to be delivered to a load. A difference in high-vacuum tubes and gas tubes is that the signal on the grid of a vacuum tube always has control of the output signal—that is, the valve can open and close partially, whereas in gas tubes the grid loses control when the gas ionizes, so that the valve is either completely open or closed. For this reason thyratrons frequently are supplied with a-c plate voltage—the valve shuts off automatically when the plate voltage cycles to zero. It will be seen that the magnetic amplifier is similar in action to a thyrathron.

Magnetic amplifiers are not new devices by any means, having been reported in use over fifty years ago. Their popularity is just now beginning to be widespread and their capabilities realized by electronics engineers. A magnetic amplifier is essentially a device which controls the a-c reactance of a coil by utilizing a d-c signal to modify the permeability of the magnetic material upon which the coil is wound.

In the early stages of development this basic idea was incorporated into devices, usually designated as saturable reactors, and used to control large electrical loads such as theatrical lighting and electric furnaces. However, the use of the SATURABLE REACTOR, the heart of the magnetic amplifier, was limited in its ability to control the load until the recent development of improved magnetic materials and efficient metallic rectifiers. The utilization of these improved materials resulted in the use of the saturable reactor in more elaborate circuits and led to the distinguishing term MAGNETIC AMPLIFIER.

Many different tradename devices, such as self-saturating magnetic amplifiers, Magamps, Transductors, and Amplistats, have been used to identify the more elaborate saturable reactor circuits. Nevertheless, in this chapter the term magnetic amplifier will be used to identify all amplifying systems which utilize the saturation of a magnetic core for the purpose of control. It is felt that this is the most popular of all terms used at the present time.

The advantages of the magnetic amplifier are principally based on the fact that it is a completely static device. With the exception of the rectifiers used, its mechanical construction is comparable to that of an iron-core transformer. There are no contacts, moving parts, filaments, or other features which account for most of the failures associated with other types of amplifiers (except for those using transistors). The need for frequent inspection and maintenance is cut to a minimum. The life of the magnetic amplifier is more or less indefinite, and it is especially suited for aircraft installation where there are adverse operating conditions such as vibration and shock.

In order to understand the theory of magnetic amplifiers, it is necessary that you possess a knowledge of magnetism and magnetic circuits. This information may be found in the Navy Training Course *Basic Electricity*, NavPers 10086, chapter 7.

Review of Inductance

Basically, the magnetic amplifier is nothing more than a controlled variable inductance in series with an a-c power source and a load. It may be recalled that any coil possesses a property of electrical inertia called inductance. The inductance of a coil may be increased by providing it with an iron-core magnetic circuit. The inductance of coils with magnetic cores may be determined with fair accuracy by the following formula:

$$L = \frac{1.256 N^2 A \mu 10^{-8}}{l}$$

Where L = Inductance in henrys
N = Number of turns
A = Area of core in square centimeters
μ (mu) = Permeability of magnetic material
l = Length of core in centimeters

PERMEABILITY is a measure of the relative ease with which flux flows in a material. The permeability of air is one (1). The permeability of the core of a coil can be increased if the air is replaced by some type of ferromagnetic material such as iron or steel. By observation of the preceding formula, it can be clearly seen that if the permeability (μ) is increased by one thousand (1,000) when the iron core is inserted, the inductance will be increased one thousand (1,000) times over the inductance of the same coil with an air core.

Figure 4–1 shows a simple magnetic amplifier where the iron core is mechanically moved in and out of the coil to vary the inductance and hence the inductive reactance of the coil. When the iron core is completely within the coil, the inductance of the coil is maximum. Therefore, the voltage drop across the inductance is maximum, and so reduces the voltage across the load resistor R_L to a low value. However, removing the core from the coil lowers the inductance of the coil (hence the impedance of the circuit), decreasing the voltage across the inductance and

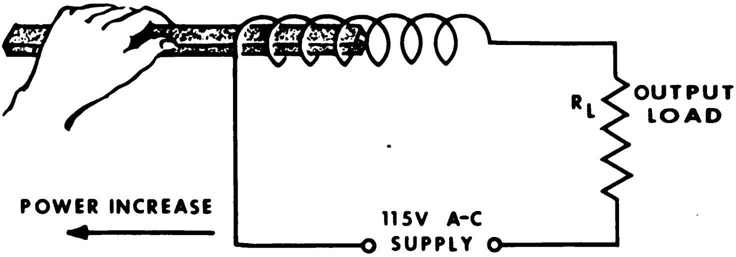


Figure 4—1.—Varying coil inductance mechanically.

increasing the voltage across the load to nearly 115 volts. In effect, this is the operating principle of a magnetic amplifier. Since it requires relatively few watts of power to move the core within the coil, which in turn can control perhaps several horsepower, the device is an AMPLIFIER.

Magnetization and Permeability Curves

Although the mechanical arrangement is effective, and some types are still in use, the present day method of controlling the permeability of the coil core is obtained by saturating the core with a relatively small amount of d-c or properly phased a-c voltage. An unsaturated core provides a relatively high impedance to the circuit. A saturated core, however, acts similar to an air core, offering practically no impedance except for the low d-c resistance of the coil.

By briefly reviewing some of the facts concerning saturation of a coil, it should be remembered that when current flows through a coil there is set up across the coil a magnetomotive force, the intensity of which depends upon the amount of current flowing through the coil. This force in a magnetic circuit may be compared to the voltage of an ordinary electric circuit. The magnetomotive force sets up a flux about the coil, which is comparable to the current of an ordinary circuit and has a density which depends on the reluctance of the core of the coil. The core reluctance, which may be compared to the resistance of an electric circuit, has a value which depends on the material forming the core. The reluctance of an air core remains constant regardless of current. This results in an increase of flux density which is proportional to the increase in both current and magnetomotive force. When a magnetic substance makes up the core of a coil, however, the reluctance is no longer constant, regardless of current. Instead, as a current begins to flow, the reluctance is very low and the flux is very high compared to that existing in an air-core coil under similar conditions. With an increase in current, the reluctance gradually increases and the rate-of-flux increase is reduced. After the current reaches a certain value, which depends on the core material used, the reluctance increases very rapidly until its value approaches that of air. In this region, around point *b* in figure 4–2, any further increase in current will produce no appreciable increase in flux. This condition is known as SATURATION.

As previously stated, an iron-core coil that is saturated acts similar to an air core coil for it offers practically no impedance to changes in current except for the low d-c resistance of the coil. This stems from the fact that the inductance of a coil is proportional to its incremental permeability, which is the ratio of a small change of flux density, ΔB, over a correspondingly small change in magnetic field intensity or ampere turns, ΔH. (Incremental $\mu = \Delta B/\Delta H$.)

This can be graphically shown by considering a typical magnetization curve, such as that shown in figure 4–2. The flux density, B, is shown in kilogausses and the magnetic field intensity, H, is shown in oersteds which are proportional to ampere turns. The inductance of the coil is proportional to the rate of change of flux density, B, with respect to magnetic field intensity (ampere turns), H. It will be seen that in the region of the curve around point *a*, a small change of ampere turns, ΔH, will produce a large change of magnetic flux density, ΔB. This represents the unsaturated condition of the coil, and therefore its inductance is large.

In the region of the curve around point *b*, the same small change of ampere turns, H will now produce only a very

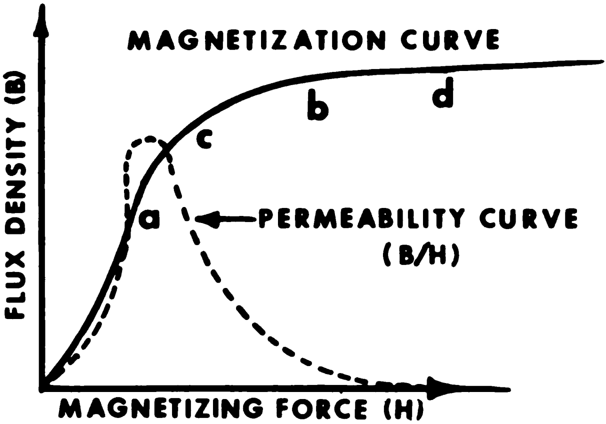


Figure 4–2.—Magnetization and permeability curves.

small change in flux density, *B*. This represents the saturated condition of the coil and its inductance in this region is very low.

An application of the basic saturable reactor may be used in a special type of filter choke that is often used in power supplies where the current drain varies considerably. They are called swinging chokes and are designed to operate on the portion of the curve between point *a* and *b*. For low values of current, their inductance values are quite high. For high values of current their inductance values are low since the core has become saturated. The air gap in the swinging choke is much smaller than in the ordinary filter choke and, consequently, the total reluctance or opposition to the magnetic lines of force through the core is small. This permits the choke to become saturated for high values of current. This type of choke has special applications in circuits where the direct-current variations are quite large, since it has been found that they give better direct voltage regulation with varying amounts of direct current. That is, the voltage drop across the choke remains nearly constant even though the amount of current varies over a wide range.

The magnetic amplifier works on the principle that varying the average magnetic field intensity will vary the inductance. Referring again to figure 4–2, the curve from the origin to the region below point *c* is quite steep but approximately straight. The inductance in this region is therefore high but constant, that is, given changes of ampere turns will produce high but constant changes in flux density. Operating the coil in this region will therefore produce little or no change in inductance for changes in ampere turns and no amplifier action will result.

The region of saturation around point *b* is likewise very flat, so that the inductance around this region is very small and changes very little with changes in ampere turns. Operation of the coil in this region will likewise be unsuitable for amplifier action.

In the curved or nonlinear portion of the curve around point *c*, the inductance changes quite rapidly with small changes of ampere turns; that is, the rate of the rate of change of flux density with respect to ampere turns is large. This region is the desired operating region of the coil for magnetic amplifier action because small changes of average ampere turns produce large and significant changes of inductance, therefore producing high gain.

It is possible to derive the permeability curve for the magnetization curve shown in figure 4–2 since the ratio B/H is the slope of the magnetization curve. This permeability curve is represented by the broken line in the figure. It clearly shows that the permeability is low for small and very large values of magnetizing force and is rather high for intermediate values of magnetizing force. The inductance of a coil can be varied by altering the magnetizing force. As illustrated in figure 4–2, as the MAGNETIZING FORCE IS ALTERED the permeability is varied, hence the inductance is also varied.

Removing the iron core physically, as shown in figure 4–1, does not actually control the effective permeability of the magnetic material since the core is actually replaced by air. In most modern applications, the saturation method is used. This not only simplifies the installation but permits a much higher speed of response, eliminates mechanical moving parts and considerably widens the range of application.

The Basic Magnetic Amplifier

The basic circuit for controlling the load power by means of a control winding is illustrated in figure 4–3. Both windings are on a common core; the primary is usually referred to as the control winding.

The primary winding is supplied with a d-c source for control purposes. A potentiometer is connected in series with this circuit and is used to control the amount of current flow. This current flow will establish a unidirectional flux (gausses) in the core at a level depending upon the amount of d-c magnetizing force (oersteds). (Oersted × 2.021 = ampere turn/inch; gauss × 6.452 = line/square inch.) The second winding is connected in series with an a-c source and the load, which is shown as a lamp.

As can be seen in figure 4–2, changes of current through the control winding corresponding to variations in magnetic field intensity (ampere turns) between the origin and point *a* will produce little or no change in inductance or permeability due to the nearly straight characteristic of the curve. In order for these changes in current to produce changes in inductance, they must take place on the curved portion, or KNEE of the curve. This means that sufficient current must flow through the control winding to place the

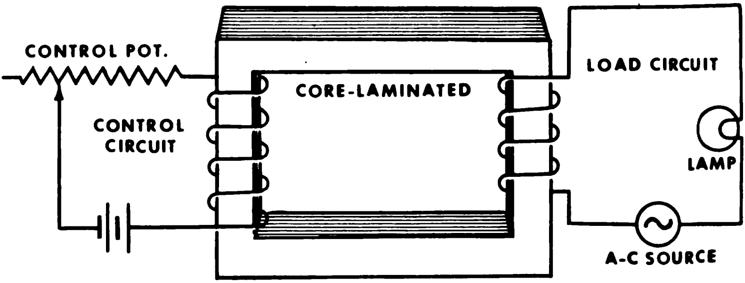


Figure 4–3.—A simple magnetic amplifier.

operating point at the knee, such as at point *c*. This is very similar to setting the operating point of a vacuum tube by means of bias.

With the coil operating on the knee of the magnetization curve, a small increase of current through the control winding will lower the inductance of the coil, or permeability of the core, because the magnetization curve's direction or slope is moving toward a horizontal direction. As a result, the a-c reactance of the load winding is decreased. The decreased impedance of the load circuit will then allow a larger current to flow, thereby increasing the power developed across the load. With the core completely saturated, the load winding reactance drops to nearly zero, leaving only the resistance of the copper wire to impede the flow of current. Under this condition, the maximum supply voltage will be applied to the load, thus the lamp will be brightest. Conversely, decreasing the current through the control winding will increase the reactance of the load coil. In the region between the origin and point *a* on the curve in figure 4–2, the core permeability, hence coil inductance, is maximum, resulting in minimum load current and, consequently, minimum power. Since the reactance of the load coil winding has been changed by varying the degree of saturation, the device is referred to as a SATURABLE REACTOR.

IMPROVED BASIC MAGNETIC AMPLIFIER

Although the explanation just given shows the basic way of controlling the core permeability, the circuit of figure 4–3 is a very inefficient magnetic amplifier because of transformer action between the two windings. The alternating flux from the secondary will induce a voltage into the control winding. If the control winding has a large number of turns, the voltage may become excessive and may even break down the insulation. Another reason why this form of magnetic amplifier is seldom used is due to the fact that the control winding would act as a short-circuited secondary. This would dissipate a considerable amount of a-c energy that is applied to the controlled winding. It is possible to prevent this loss by inserting an isolating impedance, in the form of an inductance, in series with the control winding. Another method of preventing this loss is by utilizing a THREE-LEGGED core. This method will be described in detail.

Three-Legged Core

The transformer action previously mentioned would also cause an oscillating flux in the core and the usual *B–H* hysteresis loop of the core material would be traced out during one full cycle of the a-c source voltage as in transformer operation. In order for it to function as an amplifier, sufficient d-c magnetizing force (oersteds) will be required to counteract the a-c flux, and an additional amount of d-c magnetizing force will be needed to set the operating point. The characteristics of the circuit shown in figure 4–3 are low gain, but a linear control action.

A much more satisfactory arrangement for a saturable reactor is shown in figure 4–4. This figure shows a three-legged core having an a-c winding on each outer leg connected in series and the d-c control winding on the center leg. In a saturable reactor of this type, any alternating flux through the middle leg that is produced by one of the a-c coils is balanced by the flux produced by the other a-c coil. This is true only when both a-c coils have an equal number of turns and are connected either in SERIES or PARALLEL such that the flux produced by the two coils oppose each other through the center leg. This is shown by the dotted lines in figure 4–4.

Since these forces are opposite and equal, they do not pass through the center leg but join in a common path through the outer legs of the core. This is shown by the broken lines in figure 4–4. The figure also shows that the current through the d-c winding on the center leg of the core will produce a magnetic flux as indicated by the arrows on the solid lines. The flux lines caused by the direct current flow in two paths, as shown, and magnetize the entire core. Thus, it has been shown that although the

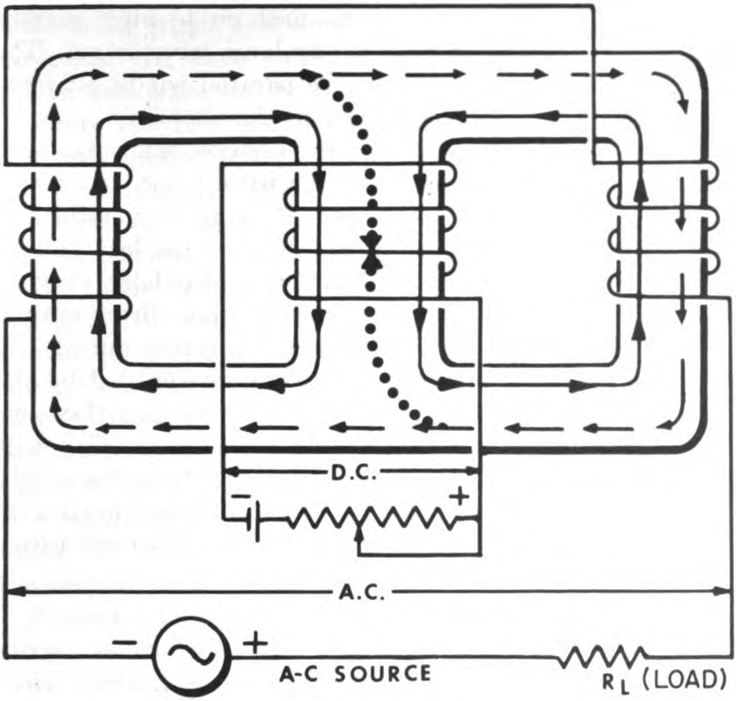


Figure 4–4.—A magnetic amplifier with three-legged core.

d-c coil is used to magnetize the cores of the a-c coils, no a-c voltage is induced into the control coil when a three-legged reactor is used.

During operation, variations of current in the control coil will vary the magnetization of the core. As has been shown previously, when the magnetizing force is altered, the permeability of the core is varied and, in turn, the inductance of the a-c coils is also varied. In other respects the three-legged magnetic amplifier functions similar to the basic circuit that is illustrated in figure 4–3.

As mentioned previously, the a-c coils can be connected either in series or parallel. The series connected a-c coils offer the advantages of higher voltage gain and faster response characteristics. The parallel connected a-c coils are capable of handling loads with medium to high current consumption as may be required by large servomotors. The time of response is longer for the parallel windings; however, this will be discussed later in the chapter.

MAGNETIC AMPLIFIER WITH HALF-WAVE RECTIFIER.—Although figure 4–3 demonstrates the basic principle used to control core saturation, this type of magnetic amplifier is relatively inefficient. This is true because the load supply voltage, which is a.c., will create a sinusoidally varying flux which will flow through the core in one direction one-half of the cycle and in the opposite direction during the other half. Thus, half of the time the flux created by the load current will impede the d-c control winding flux and the other half of the time it will aid this flux. This will shift the operating point of the amplifier from the origin (fig. 4–2) to a point of the curve whose abscissa (horizontal coordinate) corresponds to the peak value of ampere turns,

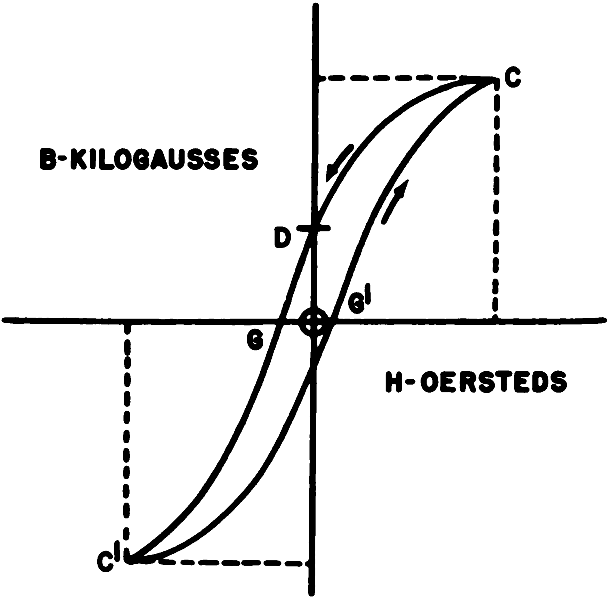


Figure 4–5.—Hysteresis loop.

back to the origin, and along a similar curve in the negative direction. In other words, the operating point of the amplifier will trace out a hysteresis curve such as is shown in figure 4–5. Because the amplifier cannot operate in this manner, the oscillating flux must be BUCKED or counteracted and then a directional flux must be added to partially saturate the core or place the operating point on the desired portion of the magnetization curve.

In order to produce sufficient flux to balance out the oscillating flux caused by the a.c. in the load winding, the ampere turns applied to the control winding would have to equal the ampere turns of the load winding. Then sufficient extra ampere turns would have to be applied to the control winding to set the operating point at the desired place on the magnetization curve. It is obvious then that this would be a very inefficient amplifier because the ampere turns required by the control loop would be greater than the ampere turns in the load circuit.

A more efficient INTERNAL feedback magnetic amplifier circuit is shown in figure 4–6. A half-wave rectifier has been inserted in the load circuit which allows current to pass in one direction only. This unidirectional load current eliminates the oscillating flux caused by the a.c. in the load circuit. Thus, the load current assists the control winding current in saturating the core. A more efficient amplifier is provided since less control power is needed

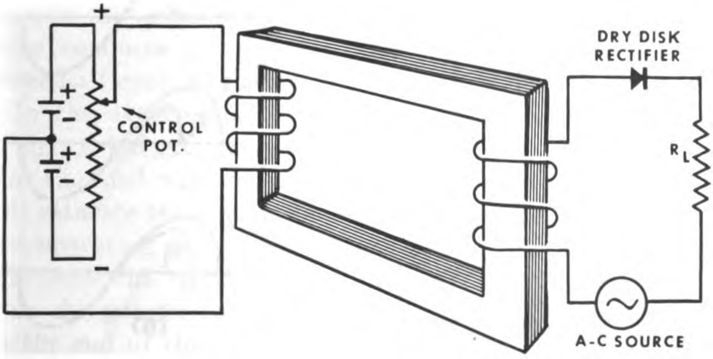


Figure 4–6.—Magnetic amplifier with half-wave rectifier.

for a given amount of control. In this figure the control circuit is so arranged that the magnetic flux resulting from the control current may either aid or oppose that resulting from the load current.

A brief explanation of the self-saturating half-wave magnetic amplifier is possible by using the magnetization curve shown in figure 4–7. This curve has been drawn with the effect of hysteresis neglected. Position *a* on this curve represents the condition of the control flux when the potentiometer in figure 4–6 is set at the positive end. Under this condition the control current produces a flux which is in opposition to the flux created by the load current. If the amplitude of the alternating current is such that it varies the core flux along the magnetization curve from point *a* to point *d* the impedance of the secondary remains large and the voltage drop across the load will be ap-

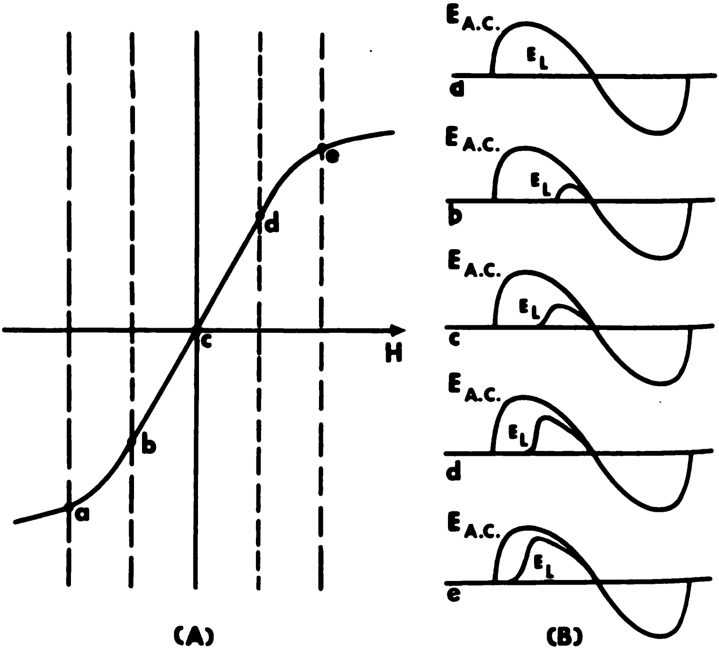


Figure 4–7.—Operation of a self-saturating magnetic amplifier.

proximately zero. The relation of the applied voltage and load current for this type of operation is represented by *a* in figure 4–7 (B). When the potentiometer is moved toward the negative end to the position where current still flows in the same direction but of less amplitude so that the control flux is at point *b* on the curve, the rectified alternating current will now vary the core flux from point *b* to point *e*. Under these conditions partial saturation of the core is achieved, resulting in a low voltage waveshape as shown at *b* in figure 4–7 (B). As the potentiometer is moved further toward the negative end, the initial flux density in the core (no load winding flux) is nearer saturation so that the inductance of the controlled winding is reduced earlier in the half cycle and larger values of load current flow. This is shown by *c*, *d*, and *e* in figure 4–7 (B).

EFFECT OF HYSTERESIS ON OPERATION.—Up to this point, in order to simplify the introduction to magnetic amplifiers, the effect of hysteresis has been neglected. In order to fully understand the operating characteristics of magnetic amplifiers, it is important to know how these characteristics are affected by the shape of the hysteresis loop.

The curve in figure 4–8 (A) represents a typical rectangular shaped *B–H* curve; the curves in (B), (C), and (D) show the operation for various amounts of control action.

Further use of figure 4–6 will be made in explaining the effects of hysteresis. This circuit actually has two distinct periods of operation. The period during which the rectifier conducts is known as the "operating period"; the other half cycle of the a.c. is known as the "control period."

In the explanation of the effect of the hysteresis loop of figure 4–8 (A), assume that control current is zero and that the load winding current is of such amplitude that it will saturate the core during peak conduction. During the first operating period, conduction through the load winding will cause the core flux to build up along the dotted line from the point of origin, *o*, to the point of saturation, *a*. At the end of this period the flux level in the coil returns to point *b* rather than to zero because of the retentivity of the core. This is called the remanence point in magnetics and leaves the core in a magnetic state, similar to a permanent magnet. Thus, with no control current the core flux will remain at point *b* and during each positive half cycle the core will saturate immediately. Under this condition the load current will be maximum for no control is exercised.

Figure 4–8 (B) shows the action when a small control current is added. The operation during the first half cycle is similar to that just described in connection with figure 4–8 (A), but during the second half cycle (control period), the flux will reset from point *b* to point *c*. This occurs because the direction of the control flux in the core is opposite to that of the operating flux.

This positioning of the residual flux is called "resetting." During the next half cycle the flux starts increasing from point *c* in the figure and a small period of this half cycle is used before the flux reaches saturation at point *a*. At this point the core is saturated and the rectifier is in maximum conduction for the remaining part of this half cycle. At the end of the operating period the flux returns to point *b* where the control period starts and resets the flux to point *c* where the cycle starts repeating itself. The output for this condition is shown as the shaded portion of the waveform of figure 4–8 (B). Figure 4–8 (C) and (D) shows the operation for increasing amounts of control action. The operation in each case is basically the same as for figure 4–8 (B).

It may be seen that the action just described is similar to that of a thyratron. The control signal sets the point of amplitude at which the source voltage causes saturation of the core and reduces the impedance in series with the load winding to a very low value. In the thyratron the control signal on the grid sets the point of amplitude at which the source voltage causes the tube to ionize, which results in a decreased impedance. The term FIRING, as it relates to the thyratron, is frequently used in connection

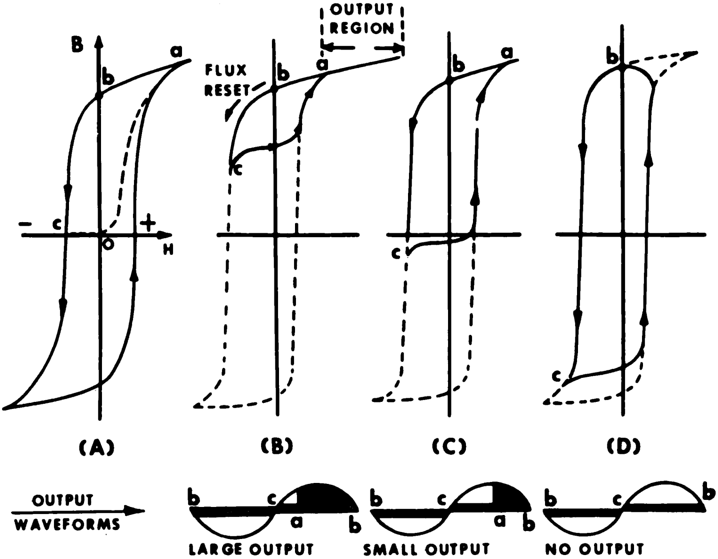


Figure 4–8.—Operation of a magnetic amplifier showing effects of hysteresis.

with magnetic amplifiers interchangeably with the term SATURATION.

USING BIAS FOR FLUX RESET.—When the core material possesses hysteresis properties that produce a rectangular-shaped *B–H* curve, it may be necessary to bias the core in order to retain control. This is accomplished by allowing a bias current to either flow through the control winding or through a separate bias winding. This bias current provides a means of resetting the flux to the initial operating point during the control period. Thus, no control current is necessary to reset the flux. Figure 4–9 shows a separate bias winding wound on the center leg of a three-legged core.

The core is usually biased so that with zero control current the load winding flux saturates the core midway in the operation cycle. This bias setting corresponds roughly to point *c* of figure 4–8 (C), and enables the control current to either advance or delay the point of saturation. In other words, if the polarity of the control current is such

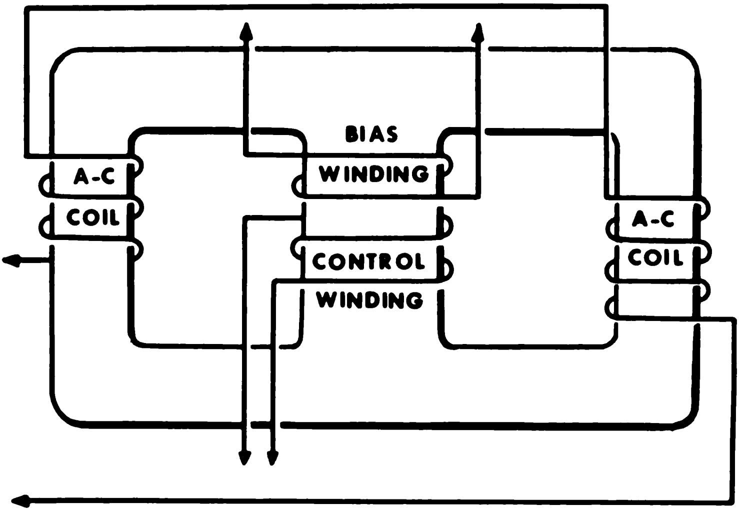


Figure 4–9.—Bias winding.

that the flux produced by it adds to the bias flux, the point of saturation will be delayed. (Control and bias flux are in opposition to load winding flux.) A control current of opposite polarity will produce a flux that opposes the bias flux and this will advance the point of saturation.

The bias may be either alternating or direct current. In most cases the polarity of d-c bias is such that it opposes the LOAD current flux. The magnitude of the bias might be such that it would reset the flux to a point between *a* and *c* of figure 4–2. There are some applications where the opposite is true; in these applications the purpose of the bias is to provide an initial d-c saturation in the core in order to obtain greater amplification of weak signals.

MAGNETIC AMPLIFIER WITH FULL-WAVE RECTIFIER.—The magnetic amplifier that has already been discussed and is shown in figure 4–6 produces a pulsating or half-wave output. In most applications of magnetic amplifiers full-wave operation is more desirable for it is more efficient since the load is energized during both halves of the a-c cycle. Full-wave operation may be obtained by using a pair of simple

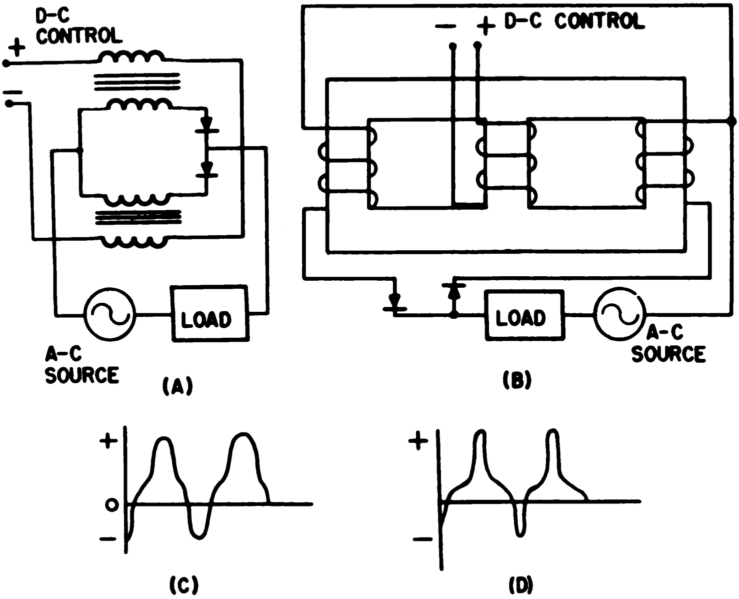


Figure 4–10.—Full-wave magnetic amplifier and output waveforms.

half-wave magnetic amplifiers operating in parallel. A typical circuit arrangement is shown in (A) of figure 4–10.

The load current is controlled by means of two control windings connected in series. Each amplifier unit contains a rectifier so that load current flows alternately in the two amplifiers. As one conducts, the core of the series coil in the other is being set by the action of the control current. And with each amplifier conducting approximately one half cycle of load current, the output variations are full-wave in nature.

Output waveforms for two different control currents are shown in (C) and (D) of figure 4–10. The waveform in (C) is produced when the control current biases the core near the point of saturation, such as point *e* in figure 4–7 (A). In this condition, saturation of the magnetic cores of the amplifiers is reached early in each half cycle, and the resulting output current variations are almost sinusoidal in shape.

When the current in the control winding biases the core to point *c* of the curve in figure 4–7 (A), the output resembles the waveform of figure 4–10 (D). The average value of the load current is now considerably less than when the control current biased the core to near saturation. Thus, as in the half-wave circuit, the output power developed in the load can be varied by controlling the load current. The output that is developed is an alternating current and is in phase with the source voltage. Figure 4–10 (B) shows a magnetic amplifier that functions similar to the one shown in (A). The major difference is that the two cores shown in (A) have been combined to form a three-legged core.

Crossover Windings

In discussing the theory of operation of the circuits shown in figures 4–6 and 4–10, it was assumed that the rectifiers have zero forward resistance and infinite back resistance. In actual practice this assumption is not valid since rectifiers do not have infinite back resistance. It should be apparent that any back current flowing through the rectifiers shown in figure 4–10 (A) during their nonconducting half cycle, will produce a magnetic flux which will tend to drive the core out of saturation. During the conducting half cycle a part of the load current would be absorbed in bringing the core back to the point of saturation, thus reducing the gain of the amplifier.

One method of counteracting this effect is by the addition of a crossover winding to the two magnetic amplifier cores. Figure 4–11 illustrates a magnetic amplifier utilizing full wave rectification and crossover windings. It should be noted that this circuit is similar to the circuit shown in figure 4–10 (A) with the addition of the crossover windings.

The crossover winding consists of a few turns which produces a magnetic field in a direction opposite to that produced by the backward current through the load winding. Referring to figure 4–11, we shall consider the action of

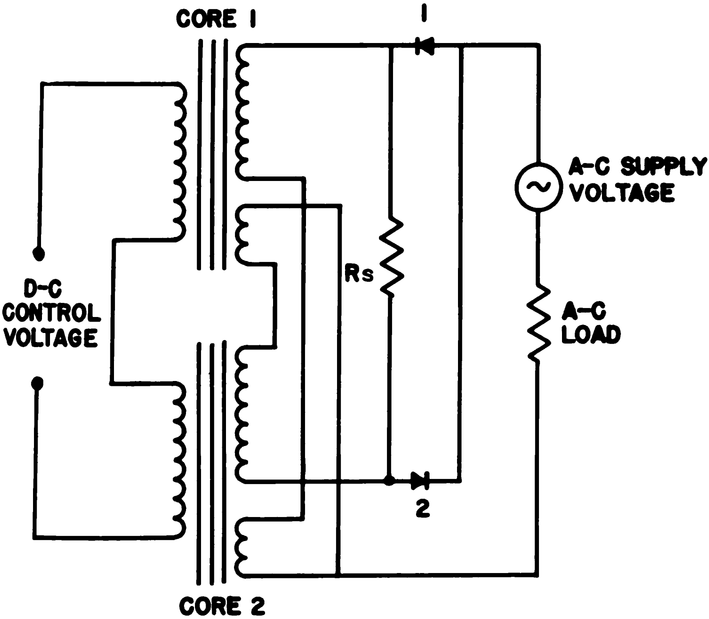


Figure 4–11.—Full-wave magnetic amplifier utilizing crossover windings.

the load and crossover windings on the two cores. Assume that during the first half cycle of the a-c supply voltage, rectifier 1 is conducting in the forward direction. The heavy current, flowing through rectifier 1 and the load winding on core 1, also flows through the crossover winding of core 2. During the same half cycle a small backward current is flowing through rectifier 2, the load winding on core 2, and the crossover winding on core 1. This small backward current flowing through the large number of turns in the load winding produces a magnetic field that is canceled by the heavy current flowing through the small number of turns of the crossover winding on core 2. A similar cancellation is achieved on the second half cycle of the a-c supply voltage by the other crossover winding.

Since the back resistance of the rectifiers will vary with temperature and applied voltage, some means must be provided to insure cancellation of the field resulting from the backward current at all times. A small constant resistance, R_s, is connected in parallel to the high, but variable, back resistance of the rectifiers. Each rectifier is shunted during its nonconducting half cycle by the series combination of R_s and the conducting rectifier. The variations in the back resistance will now have no noticeable effect on the quantity of backward current through the load windings.

Use of External Feedback in Magnetic Amplifiers

It is possible to change some of the characteristics of a magnetic amplifier by the use of external feedback. (NOTE: The action of rectifiers in series with the load current discussed earlier in this chapter constitutes internal feedback.)

Feedback is the returning of a portion of the output of an amplifier stage to the input of that or a preceding stage and may be either positive or negative depending on the effect desired. Regenerative or positive feedback makes the circuit more sensitive to change in control current; thus, the power gain of a single stage may reach 40 to 50 db. However, this type of feedback has two disadvantages for it increases the time-lag characteristics of the amplifier and may also cause instability. Degenerative or negative feedback reduces the gain of the amplifier; however, it increases the linearity of the magnetization curve and reduces the time-lag characteristics of the amplifier.

The curves in figure 4–12 illustrate the effect of both positive and negative feedback on load current as a function of input control current. It should be noted that the same amount of d-c current is needed to saturate the core regardless of the amount of feedback provided. However, when using positive feedback, less input control current is required to saturate the core since the feedback current aids the control current toward this end. The gain characteristics of magnetic amplifiers with positive and negative feedback may be compared by studying the curves shown in figure 4–12.

A schematic diagram of two magnetic amplifier circuits utilizing external feedback is shown in figure 4–13. Feed-

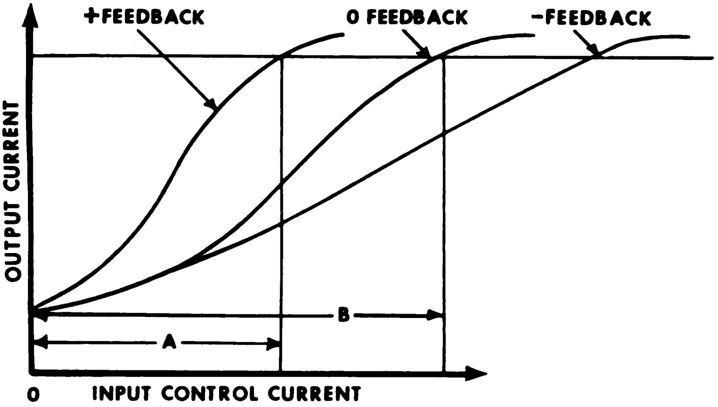
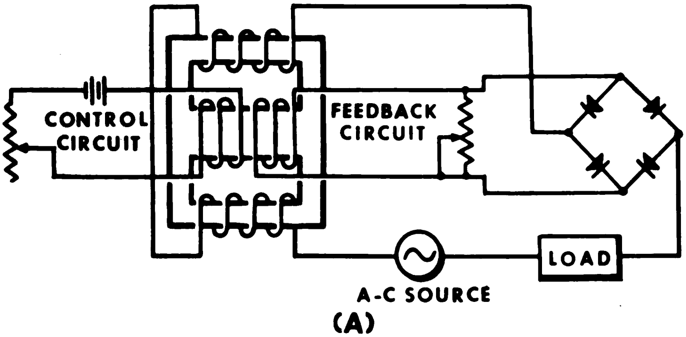


Figure 4—12.—Effects of external feedback.



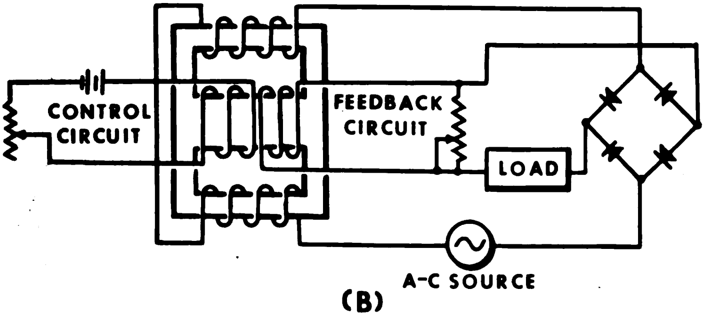


Figure 4—13.—Magnetic amplifiers using external feedback.

back is provided by an additional winding on the center leg of each core. The d-c current flowing through the feedback winding creates a magnetic field which either aids or opposes the magnetic field created by the control current.

In (A) of figure 4–13 the a-c load current is rectified prior to being fed through the feedback winding. It should be noted that the feedback current consists of the total load current and it will always flow in the same direction regardless of the input signal. To change the feedback from regenerative to degenerative or vice versa, the feedback winding connections must be reversed.

Figure 4–13 (B) illustrates the use of external feedback in a magnetic amplifier supplying a d-c load. The amount of feedback is controlled in both circuits by the setting of the potentiometer paralleling the feedback winding.

Earlier in the discussion it was mentioned that the time of response of a magnetic amplifier was affected by feedback. Since this characteristic largely determines their application, we shall discuss this aspect further. The ordinary saturable reactor type, or saturable transformer, requires a certain time for a control action to take effect since the action is applied to an L–R control circuit. The time of response is usually proportional to the time constant of the d-c input control circuit. The time constant for this inductive circuit may be determined by the equation

$$t = \frac{L}{R}$$

where t is in seconds.

L is inductance in henrys of the control winding.

R is the resistance in ohms of the control winding.

This time constant may be reduced by increasing the control circuit resistance, but this causes a control power loss. Degenerative feedback can be employed to do the same if the reduced gain can be tolerated. A normal arrangement would be to apply degenerative feedback and add more stages in cascade. When stages are cascaded, a d-c output of the first stage is applied to the control winding of the next stage, and so on.

Magnetic Amplifiers Using Toroidal Cores

In the discussion of magnetic amplifiers in this chapter, it has been assumed that the cores were constructed in such a manner to meet the characteristics established by figures 4–5 and 4–8. For optimum performance, the laminations of a magnetic amplifier core should have the effective air gap as small as possible and be very thin to reduce eddy current effects to a minimum. The usual interleaving technique found in conventional transformer core construction is unsatisfactory for saturable reactors in magnetic amplifiers. The many small air gaps provided by butt joints of the standard *E* core distort the magnetization curve, thus making it inadequate for peak performance necessary in most applications in fire control equipment. Special design of the *E* core has improved its characteristics by increasing the overlap of the laminations for a greater portion of the magnetic path; however, its performance is somewhat below that desired.

A method of construction commonly found in aviation fire control equipment makes use of toroidal cores. A toroidal core is made by spirally winding a relatively narrow silicon steel tape forming a circular or rectangular core as required. The tape cores are mounted in loose fitting insulated containers to provide support for the multilayer windings without placing mechanical strain on the cores.

Since toroidal cores have no center leg, two are required in most amplifiers. Figure 4–14 illustrates a basic magnetic amplifier utilizing two cores. The control windings are connected in series-aiding so that a common control current can saturate both cores. The a-c load windings are connected in series-opposing to minimize the alternating current induced in the control circuit.

The physical arrangement of the various windings on the cores will greatly affect the performance of the magnetic amplifier. They must be wound in such a way that leakage effects are reduced to a minimum and the circulation of alternating currents in the d-c control, bias, and feedback windings are minimized.

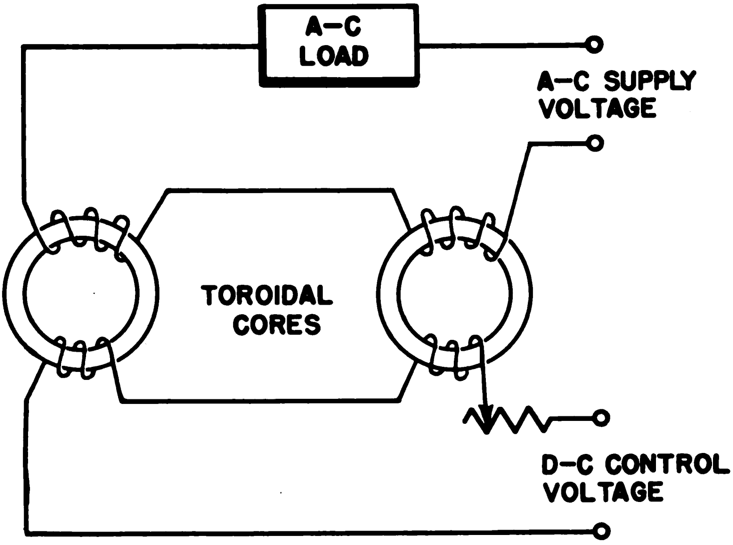


Figure 4-14.—Magnetic amplifier utilizing toroidal cores.

Typical magnetic amplifiers utilizing toroidal cores will be discussed under magnetic amplifier applications. The use of bias, feedback, and crossover windings on toroidal cores will also be discussed later in the chapter.

Applications of Magnetic Amplifiers

The magnetic amplifier has found application in almost all circuits which use vacuum tubes and many which do not. They may be found in such circuits as audio amplifiers, voltage regulators, servo amplifiers, computer counting and dividing circuits, and many high frequency circuits. However, the Aviation Fire Control Technician will be mainly concerned with their application in servo systems and in the various operations of computers.

ELECTRONIC POWER SUPPLY REGULATOR.—Many aviation electronic equipments contain voltage regulated power supplies. The accuracy of the voltage produced by these supplies is important in so far as proper operation and maximum life of the equipment is concerned. Present day

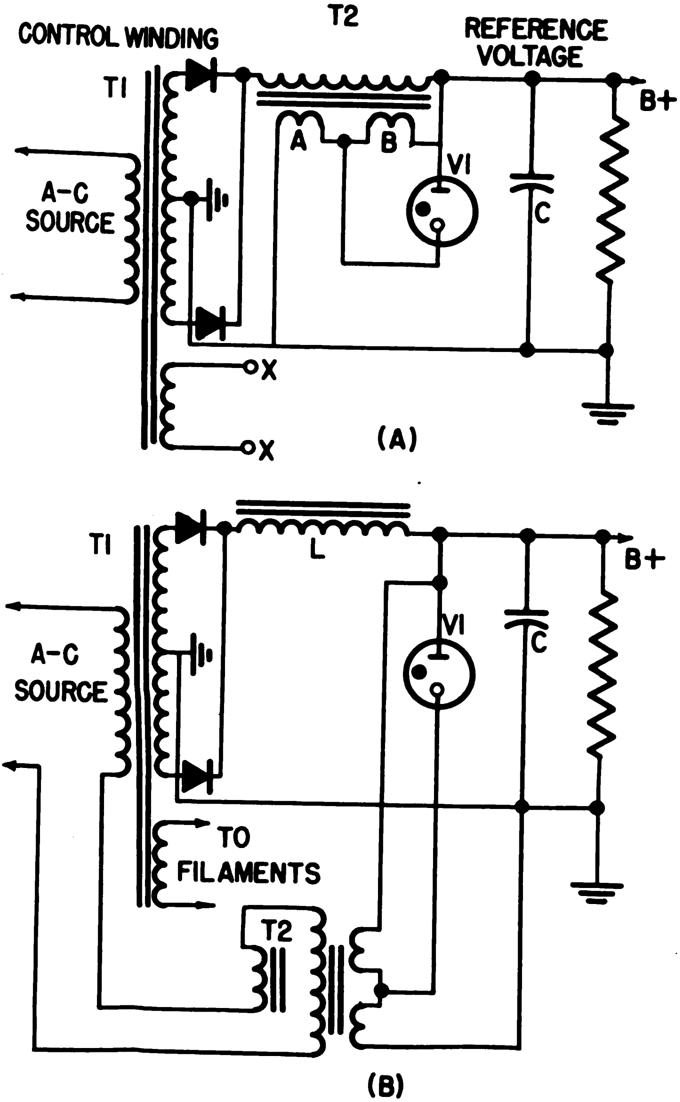


Figure 4–15.—Power supply using magnetic amplifier voltage regulator.

electronic equipments contain many timing, waveshaping, and other critical circuits that require a constant d-c voltage source.

Figure 4–15 (A) shows a power supply which uses a magnetic amplifier to regulate the d-c output voltage. In this circuit the conventional filter choke has been replaced by a saturable reactor T_2. The voltage regulator (VR) tube V_1 produces a constant reference voltage across coil B and acts as a current amplifier for the control winding A. Coils A and B control the saturation of T_2, hence, the inductance of the load winding. This action effectively transfers filter capacitor C to the other side of the choke when the core is saturated. The end result is that the power supply alternates between a choke input and a capacitor input type of supply, thus a constant voltage output is produced.

Figure 4–15 (B) shows a variation of figure 4–15 (A) in which saturable reactor T_2 is connected in series with the primary of power transformer T_1. An advantage of this circuit arrangement is that a regulated filament voltage is also produced.

The significance of constant filament voltage is appreciated when it is realized that an estimated 80 percent of all electronic failures can be directly traced to tube or capacitor failures—this does not include transformer, choke, and resistance failures which can usually be traced to overloads occurring during these failures.

Servo systems.—One of the most common uses of magnetic amplifiers in aviation today is in connection with servo systems. Figure 4–16 illustrates the use of a magnetic amplifier as the output stage of a servo amplifier. The function of the servo amplifier is to amplify the servo error signal sufficiently to drive the servomotor. For a brief review of servo systems, refer to chapter 17 of *Basic Electricity*, NavPers 10086.

Before discussing the magnetic amplifier, let us briefly review the operation of an a-c servomotor. The output of the servo amplifier is connected to one of the motor wind-

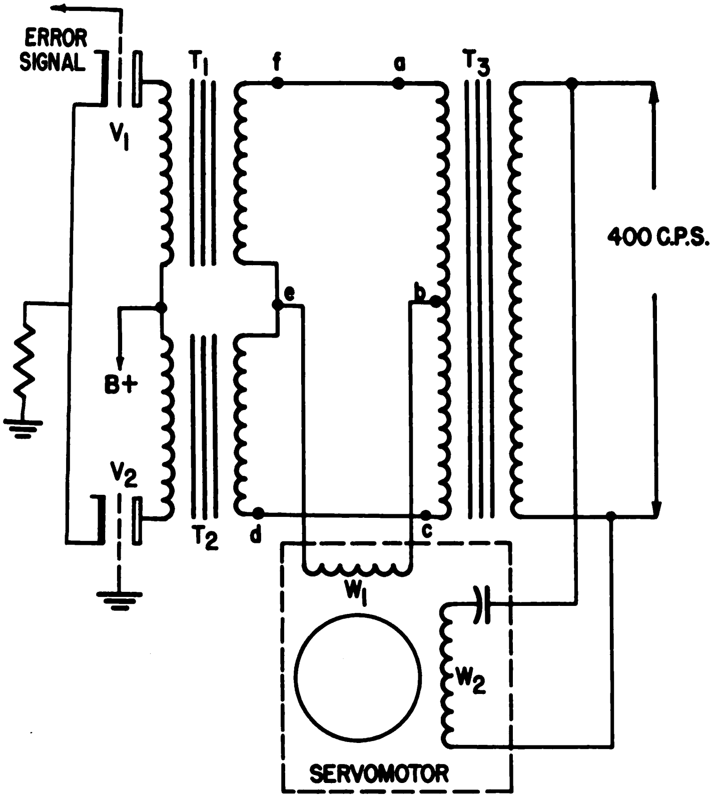


Figure 4–16.—Magnetic amplifier used as an output stage of a servo amplifier.

ings (controlled winding) while the other winding (uncontrolled winding) is connected across the a-c source in series with a capacitor. The capacitor provides the required 90-degree phase shift necessary to cause motor rotation. The phase relationship of the current through the two windings determine the direction of rotation of the servomotor.

The input to the amplifier shown in figure 4–16 is a d-c error signal and is applied to the grid of V_1. Tubes V_1 and V_2 constitute a cathode-coupled paraphase amplifier working into two saturable reactors (magnetic amplifiers).

The secondaries of the two saturable reactors and the two halves of the secondary of T_3 form an a-c bridge circuit. The motor winding W_1 is connected across the bridge as shown. With a zero error signal applied, both tubes draw equal amounts of plate current partially saturating T_1 and T_2. Since the degree of saturation of the two saturable reactors is equal, the bridge circuit is still balanced and no current will flow in W_1.

When a positive error signal is applied, V_1 will conduct heavily while V_2 will be near cutoff. At this time the secondary inductance of T_1 will be practically zero. Motor winding W_1 will be effectively connected across points *a* to *b* of T_3 and supplied with an a-c source. Also at this time the secondary inductance of T_2 will be very large (effectively an open circuit).

In a similar manner, when V_2 conducts heavily, V_1 will be near cutoff, the secondary inductance of T_2 will be near zero, and the secondary inductance of T_1 will approach maximum. Under these conditions, motor winding W_1 is now effectively connected between points *b* and *c* of T_3 and supplied an a-c voltage that is 180 degrees out of phase with the previous condition.

COMPUTER SYSTEMS.—The Aviation Fire Control Technician will find frequent application of magnetic amplifiers in computer systems.. Figure 4–17 illustrates a typical magnetic amplifier used in a computing operation. It consists of five windings on two toroidal cores of high permeability. The a-c winding, half of which is wound on each core, is the output winding of the amplifier. The remaining windings are wound continuously over both cores.

The two halves of the output winding are connected in parallel. Each branch of this winding is connected to the a-c source through a diode rectifier which permits current to flow through the two branches on alternate half cycles of the input. The two branches are connected so that current flow around the two magnetic cores is always in the same direction. Thus, the effect of pulsating, direct-current flow around the magnetic cores is obtained.

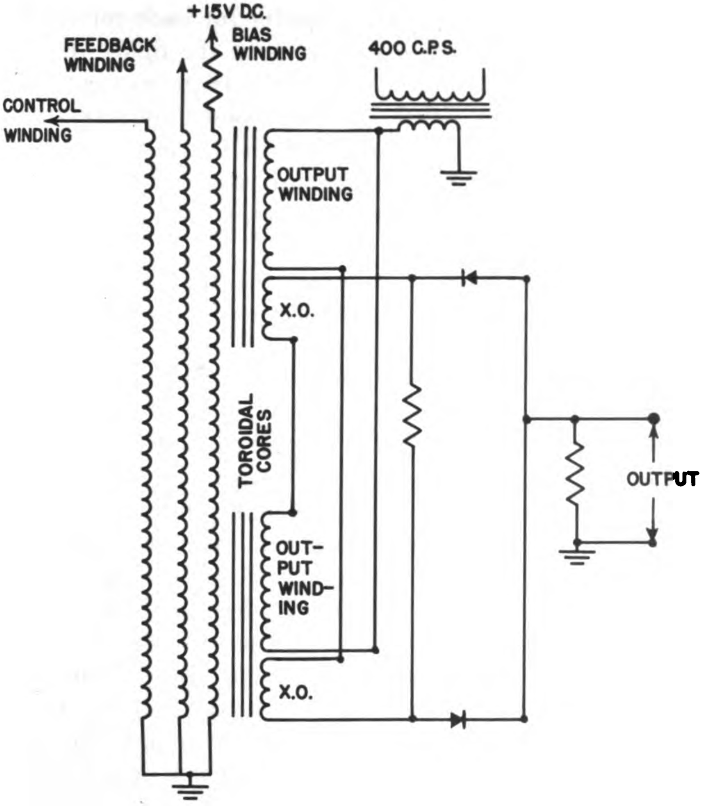


Figure 4–17.—Magnetic amplifier used in computing operations.

The pulsating current passing through the output winding causes a varying magnetic field to form, with flux lines passing through and around the magnetic cores. The variation of the magnetic field induces a back e.m.f. that opposes current flow within the windings. Since the magnetic cores will support only so many lines of flux, the variation of the magnetic field may be decreased by passing a direct current through the control winding and partially saturating the magnetic cores. This decreases the inductive reactance of the output winding and permits more current to flow.

The crossover winding compensates for back current flow through the diodes. It can be seen in the figure that flux from a back current flow through the large segment of the output winding on either core is opposed by flux from a forward current flow through the small crossover winding on the same core. The number of turns of the crossover winding has been calculated to compensate for back current flow.

In most applications in computers, the feedback winding is connected to the output from the amplifier. This provides positive feedback which compensates for some of the internal losses of the amplifier and increases the gain.

The bias winding increases the operating range of the amplifier and provides better control needed in computers. A bias voltage, which normally is approximately 15 volts, is applied to the bias winding. Current flow through this winding nearly saturates the magnetic cores of the amplifier. The peak value of the pulsating direct current through the output winding and through the feedback winding produces a magnetic field OPPOSITE TO that created by the BIAS winding and of sufficient magnitude to nearly saturate the cores. A d-c input signal applied to the control winding aids the field produced by current flow through the output winding and drives the cores to saturation over a part of each half cycle of the a-c input. This decreases the inductive reactance of the output winding, producing a large output signal for a relatively small input. Thus, the bias winding field opposing that of the control, load, and feedback windings extends the operating range of the amplifier.

QUIZ

1. A magnetic amplifier is a
   a. variable load in series with an a-c source
   b. load and an a-c source in parallel with a variable inductance
   c. controlled variable inductance in series with an a-c power source and a load
   d. variable inductance in parallel with an a-c power source and a load

2. How is it possible to control the inductance of a given coil?
   a. By controlling the permeability of the core
   b. By increasing the current flow in the coil
   c. By increasing the voltage applied to the coil
   d. By controlling the frequency applied to the coil

3. When the iron core is fully retracted from the coil shown in figure 4–1, the voltage drop across the output load is
   a. minimum a.c.
   b. zero
   c. maximum d.c.
   d. maximum a.c.

4. An electronic method of controlling the permeability of a coil core is obtained by
   a. decreasing the number of turns on the coil
   b. increasing the number of turns on the coil
   c. using a properly designed magnetic core material
   d. saturating the core with a direct current or properly phased alternating current

5. The permeability of a material is
   a. a measure of the relative ease with which flux flows in it
   b. a measure of its conductance
   c. represented by the Greek letter α
   d. represented by the Greek letter λ

6. On the magnetization curve shown in figure 4–2, where is the point of operation that will give the desired magnetic amplifier action?
   a. Point *b*
   b. Point *a*
   c. Point *d*
   d. Point *c*

7. What is the advantage of using a three-legged core saturable reactor in preference to using a two-legged one?
   - a. It will eliminate transformer action between the secondary winding and the control winding
   - b. It is adaptable only to saturable reactors
   - c. There will be more current drawn from the a-c source
   - d. A-c voltage will be induced into the control winding

8. Referring to figure 4–6, where must the control potentiometer be positioned to give maximum saturation of the core material?
   - a. At the negative end of the voltage divider
   - b. At the midpoint on the voltage divider
   - c. Between the midpoint and the positive end of the voltage divider
   - d. At the positive end of the voltage divider

9. The purpose of crossover windings is to
   - a. increase the internal feedback
   - b. reduce the effect of backward current through the rectifiers
   - c. bias the amplifier to increase its efficiency
   - d. prevent a-c feedback into the control winding

10. What is the effect of using external positive feedback in magnetic amplifiers?
    - a. Decreased gain and decreased time of response
    - b. Increased gain and decreased time of response
    - c. Increased gain and increased time of response
    - d. Decreased gain and increased time of response

11. The action of rectifiers in series with the load current produces what type of feedback?
    - a. Negative
    - b. External
    - c. Internal
    - d. Degenerative

12. The time of response of a magnetic amplifier may be determined by which of the following?
    - a. $t = R/L$
    - b. $t = RL$
    - c. $t = 2/RL$
    - d. $t = L/R$

13. The linearity of a magnetic amplifier's output may be improved by
    - a. use of positive external feedback
    - b. use of negative external feedback
    - c. increasing the input voltage source
    - d. decreasing the input voltage source

14. Toroidal cores are more efficient because they
    a. have no third leg to distort the magnetic field
    b. may be made circular
    c. may be used in pairs
    d. have a minimum air gap

15. Referring to figure 4–17, the output is
    a. a d-c voltage proportional to the control winding current
    b. an a-c voltage proportional to the control winding current
    c. independent of the bias voltage
    d. one-half the input frequency

16. A saturated iron-core coil offers
    a. an infinite impedance to current flow
    b. practically no impedance to current flow
    c. a high d-c resistance
    d. an infinite d-c resistance

17. The magnetic amplifier works on the principle that varying the magnetic field intensity will vary the coil's
    a. frequency stability
    b. d-c resistance
    c. inductance
    d. frequency response

18. The capacitor in series with the W_2 winding in figure 4–16
    a. acts as a filter network with W_2
    b. acts as an a-c ground
    c. provides harmonic filtering
    d. provides the necessary phase shift

19. In figure 4–14 the a-c load windings are connected in series-opposing
    a. to minimize the alternating current induced in the control circuit
    b. to amplify the alternating current induced in the control circuit
    c. so that a common current can saturate both cores
    d. to filter harmonics out of the load circuit

20. External degenerative feedback in a magnetic amplifier
    a. increases the gain
    b. decreases the linearity
    c. reduces the gain
    d. increases the time-lag

CHAPTER 5

SERVOMECHANISMS

If you analyze the word servomechanism, you will find it means a machine that serves. In other words, a servomechanism takes an order and carries it out, correcting any errors caused by outside forces as well as any errors made within itself. In carrying out the order, a servomechanism determines the type and amount of difference between what should be done and what is being done.

Because of these abilities, a servomechanism plays an important part in the design of aviation fire control equipment; for example, to keep a turret aimed with the correct lead while the defending aircraft is flying an evasive course. The basic theory of servomechanisms was discussed in chapter 17 of Navy Training Course, *Basic Electricity*, NavPers 10086, and it is recommended that this chapter be reviewed before going further in this course.

BASIC TYPES OF CONTROL

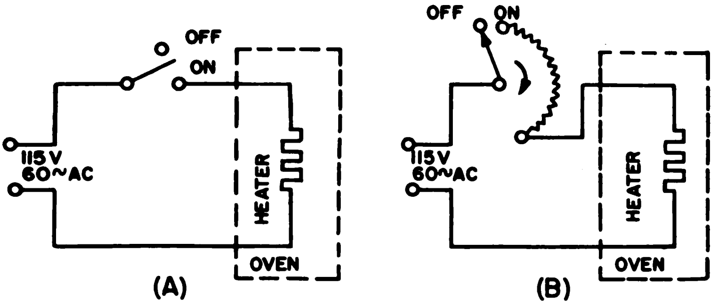
A servomechanism, in carrying out its orders, accomplishes its task by exercising CONTROL over a source of power. Control implies the conditional use of an external source of power, which in most cases is substantially greater than the controlling power. Almost unlimited quantities of mechanical or electrical power can be controlled by opening or closing a simple valve or switch.

Since a servomechanism is a device for exercising control of some external source of power, it is well to consider the various basic types of controls and their characteristics. A control system may encompass the control of electrical, mechanical, hydraulic, pneumatic, or thermal units, or of various combinations of different units.

The simplest form of control can be illustrated by the elementary electric circuit shown in (A) of figure 5–1. The circuit contains a source of power; a switch, or controlling device; and a load consisting of a heater element. The components are connected in series; and when the switch is closed, energy flows to the load and performs useful work; when the switch is opened, the energy source is disconnected from the load. Thus, the flow of energy is either zero or a finite value determined by the resistance of the circuit. Operation of this general type is called DISCONTINUOUS CONTROL.

In (B) of figure 5–1, the circuit shown is modified by substitution of a rheostat for the switch; and the circuit now provides CONTINUOUS CONTROL. By displacing the rheostat contact, the circuit resistance is varied continuously over a limited range of values. The energy expended in the load is then varied or regulated over a corresponding range rather than by intermittent, or on-off, action as in discontinuous control. These examples represent a fundamental property of control systems in general: The energy required to control the system is small compared with the quantity delivered to the load.

As discussed above, the power source is controlled di-



DISCONTINUOUS CONTROL

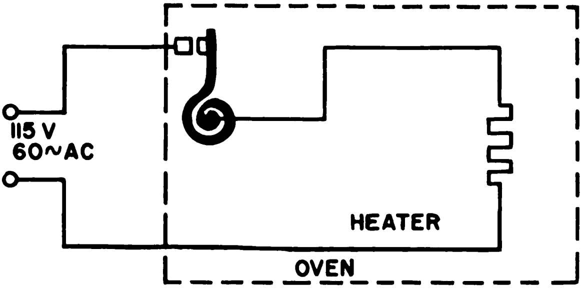
CONTINUOUS CONTROL

Figure 5–1.—(A) Discontinuous control; (B) continuous control.

rectly by the manual adjustment of a switch or of a rheostat. In more complicated systems, control signals are applied to the power device by the action of an electrical or mechanical device rather than by manual means. The device which develops the control signals is called an AUTOMATIC CONTROLLER; and the entire system is known as an AUTOMATIC CONTROL SYSTEM.

Automatic control systems can be divided into two basic types: OPEN-LOOP and CLOSED-LOOP systems. An example of an automatic open-loop control system is an electric timer used to control the action of the heating element. (See fig. 5–1.) Although the heater is entirely automatic, the temperature of the oven in no way affects the switching action of the timer. The initiating action (timer) is independent of the results obtained.

If a bimetallic spring type thermostat is substituted for the switch as shown in figure 5–2, the temperature of the oven will control the power applied to the heater. When the temperature rises to a predetermined level, the thermostat will open the circuit. When the temperature falls slightly below this point, the spring cools, closing the contacts, and the heater again begins operation. The controlling device is affected by the results of the load and is known as a CLOSED-LOOP system.



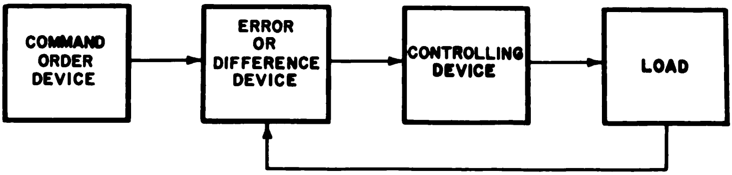
CLOSED LOOP AUTOMATIC DISCONTINUOUS CONTROL SYSTEM

Figure 5–2.—Closed-loop, automatic, discontinuous control system.

All controls described are used to regulate the power to the heater. Thus, they may be classified as REGULATING controls. An example of their application in fire control equipment may be found in the regulation of pressure, temperature, and speed.

Another type of control, based on its application, is the POSITIONING control. As the name implies, the positioning control is used to position a shaft or some other form of load. Positioning controls have wide application in aviation fire control and are used in most all fire control equipment. The basic fundamentals applicable to regulating controls also apply to positioning controls. Thus, positioning controls may be CONTINUOUS or DISCONTINUOUS, OPEN-LOOP or CLOSED-LOOP, and MANUAL or AUTOMATIC. However, most controls with which the Aviation Fire Control Technician will be concerned will be of the continuous, automatic, closed-loop type.

To insure a thorough understanding of this type of control, let us briefly review what it encompasses. A block diagram of such a system is shown in figure 5–3. An order is issued by the command order device to change the position of the load to a certain location. The error or difference measuring device receives the order, compares it with the present position of the load, and issues an order to the controlling device based on the difference between the ordered location and present location. This is a continuous process until the load reaches its ordered position.



BLOCK DIAGRAM SHOWING CONTINUOUS, AUTOMATIC, CLOSED-LOOP TYPE OF CONTROL SYSTEM

Figure 5–3.—Block diagram showing continuous, automatic, closed-loop type of control system.

A type of automatic closed-loop positioning control system frequently used in aviation fire control equipment is the SERVOMECHANISM. A servomechanism may be defined as a feedback automatic control system that measures the output, compares it with the input, and uses the resulting error signal to control comparatively large amounts of load power.

BASIC SERVOMECHANISMS

The essential components of servomechanisms are the DATA TRANSMISSION SYSTEM, the SERVO CONTROL AMPLIFIER, and the SERVOMOTOR. These components are shown in the block diagram of figure 5–4 and will be discussed in the following paragraphs.

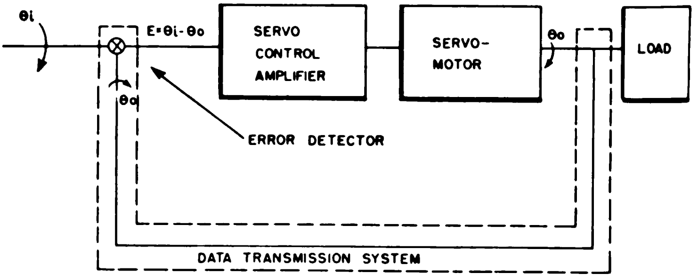


Figure 5–4.—Simplified block diagram of servomechanism.

Data Transmission Systems

The functions of the data transmission system are:

1. To measure the servo output.
2. To transmit or feed back the signal, which is proportional to the output, to the error detector (a differential device for comparing two signals).
3. To compare the input signal with the feedback signal to the servo.
4. To transmit to the servo amplifier a signal which is proportional to the difference between the input and output signals.

The signal obtained by comparing the servo input and output is called the servo error, and is represented by the symbol E. Figure 5–4 shows that the error, E, is the difference between the input θ_i and the output θ_o.

$$E = \theta_i - \theta_o$$

In many servo systems the physical location of the servo input device and output device are remotely located from each other and may also be remotely located from the servo amplifier. This requires some means of transmitting the output information back to the device receiving the input command. This transmission system as well as the comparing device (called an error detector) is part of the data transmission system.

Servo Amplifier

The function of the servo amplifier is to receive the error signal from the error detector, to amplify it sufficiently to cause the output member to position the servo load to the commanded position, and to transmit the amplified signal to the servomotor.

Servomotor

The servomotor functions to position the servo load. The motor must be capable of positioning the load so as to require a minimum response time based on the requirements of the system.

ERROR DETECTORS

The component of the data transmission system that compares the input with the servomechanism output is the ERROR DETECTOR. An error detector can be either a mechanical or an electrical device. A simple form of a mechanical error detector is the differential. (NOTE: The operation of the differential is explained in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388.) However, in aviation fire control equipment, error detectors are mainly electrical devices due to their adaptability to widely separated or remotely installed components. The electrical devices that are mainly utilized are of either the potentiometer (resistive) or one of several magnetic devices.

Electrical error detectors may be either a-c or d-c devices depending upon the requirements of the servo system. An a-c device used as an error detector must compare the two input signals and produce an error signal of which the phase and amplitude will indicate both direction and amount of control necessary for correspondence. A d-c device differs in that the polarity of output error signal determines direction of the correction necessary.

Potentiometer Type

Potentiometer error detector systems are generally used only where the input and output of the servomechanism has limited motion. They are characterized by high accuracy, small size, and the fact that a d-c or an a-c voltage may be obtained as the output. Their disadvantages include limited motion, a life problem resulting from the wear of the brush on the potentiometer wire, and the fact that the voltage output of the potentiometer changes in discrete steps as the brush moves from wire to wire. A further disadvantage of some potentiometers is the high drive torque required to rotate the wiper contact.

An example of a balanced potentiometer error detector is shown in figure 5–5. As stated above, the purpose of the circuit is to give an output error voltage which is proportional to the difference between the input and output signals.

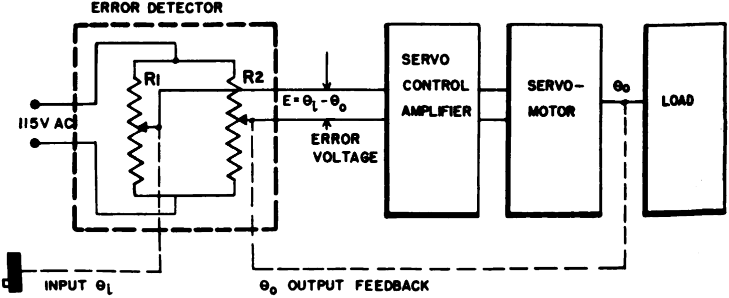


Figure 5–5.—Balanced potentiometer error detector system.

The command input shaft is mechanically linked to R_1 and the load is mechanically linked to R_2. An electrical source of 115 volts a.c. is applied across both potentiometers.

When the input and output shafts are in the same angular position, they are in correspondence and there will be no output error voltage. If the input shaft is rotated, moving the wiper contact of R_1, an error voltage will be applied to the control amplifier. This error voltage is the difference of the voltages at the wiper contacts of R_1 and R_2. The output of the amplifier will cause the motor to rotate the load and the wiper contact of R_2 until both voltages are equal; thus, there is no output error voltage.

Figure 5–5 illustrates R_1 and R_2 grouped together. In actual practice the potentiometers may be positioned remotely from each other, with R_2, the output potentiometer, being located at the output shaft or load. This remote location of one of the components does not remove it from being a part of the error detector.

E Transformers

A type of magnetic device which is used as an error detector is the E TRANSFORMER. Its application is useful in systems that do not require the error detector to move through large angles. A simplified drawing, which is one of several possible devices in this category, is shown in figure 5–6.

The primary excitation voltage is applied to coil A on the center leg of the laminated core. The coupling between coil A and the secondary windings, coils B and C, is controlled by the armature which is displaced linearly by the input signal. At the position of the armature where the coupling between the windings is balanced, the output voltage is a minimum because of the series-opposing connections of the secondary windings. The phase of the output voltage on either side of the voltage null differs by 180 degrees, and by proper design of the transformer the amplitude can be made proportional to the displacement of

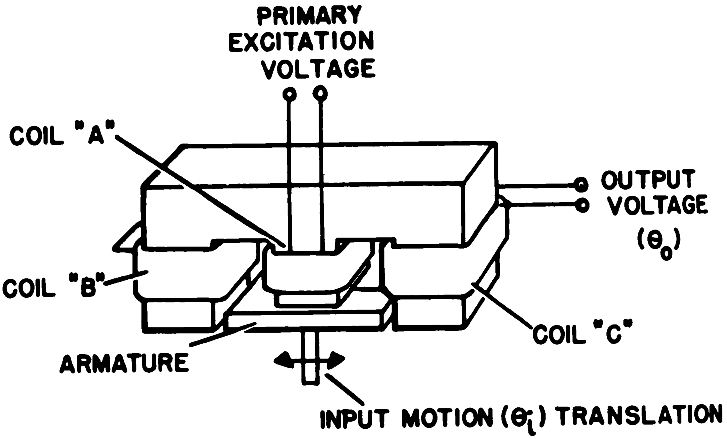

PRIMARY EXCITATION VOLTAGE
COIL "A"
OUTPUT VOLTAGE (θ_o)
COIL "B"
COIL "C"
ARMATURE
INPUT MOTION (θ_i) TRANSLATION

Figure 5–6.—E transformer error detector.

the armature from its null voltage position. This type of error detector possesses the advantages of small size and high accuracy, but has the disadvantage of permitting only limited input motion.

Control Transformers

A commonly used magnetic error detector is the synchro CONTROL TRANSFORMER which is used in conjunction with a synchro data transmission system. Synchros have been developed to a point of relatively high accuracy, low noise level, reasonably small driving torques, and excellent life. These qualities are also applicable to the synchro control transformer. A primary advantage over other types of error detectors is its unlimited rotation angle; that is, both the input and the output to the synchro control transformer may rotate through unlimited angles. Among the disadvantages of synchros (including the synchro control transformer) are the large size necessary to maintain high accuracy, the power consumed, and the fact that the output supplied to the servo control amplifier is always a-c modulated with the servo error and must be demodulated in the servo control amplifier if it is to be applied to a d-c servomotor.

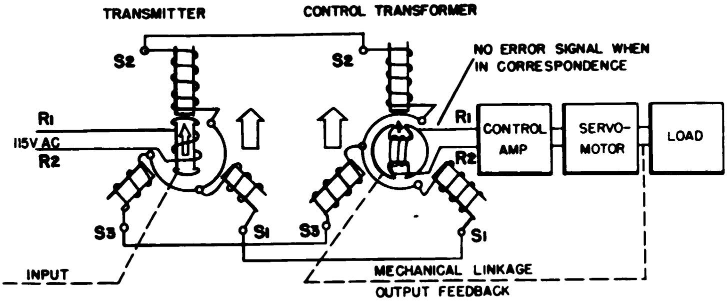


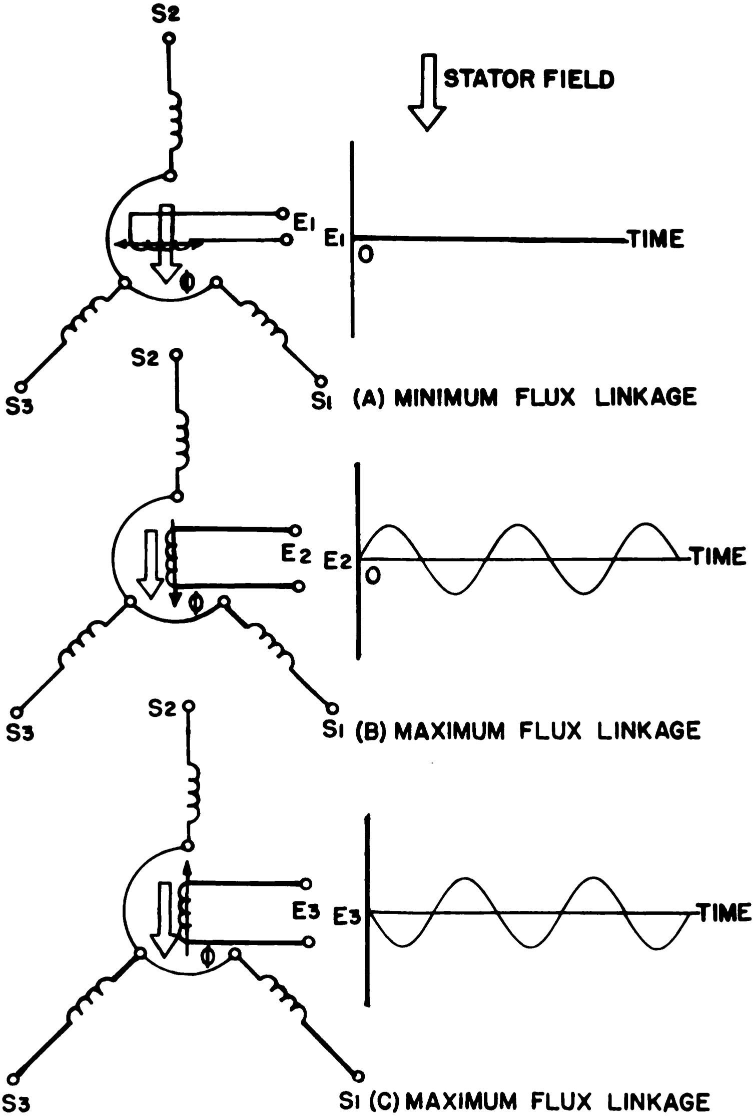
Figure 5–7.—The control transformer as an error detector.

The synchro data transmission system is comprised of a synchro generator, a synchro control transformer, and in some cases a differential generator for additional servo inputs. The synchro generator transforms the motion of its shaft into electrical signals suitable for transmission to the synchro control transformer, which comprises the error detector. (See fig. 5–7.)

The stator of the generator consists of three coils spaced 120 electrical degrees apart. The voltage induced into the stator windings is a function of the generator rotor. These voltages are applied to the three similar stator windings of the synchro control transformer. The voltage induced in the rotor of the synchro control transformer depends upon the relative position of this rotor with respect to the direction of the stator flux.

The variation of the synchro control transformer output voltage as a function of the rotor position relative to an assumed stator flux direction is shown in figure 5–8. While there are two positions of the rotor, 180 degrees apart, where the output voltage is zero, only one corresponds to a stable operating position of the servo.

In cases where a synchro differential generator is used for additional inputs to the servo system, it is connected between the synchro generator and the synchro control transformer. (See fig. 5–9.) When the synchro differential rotor is in line with its stator windings, the differential generator acts as a one-to-one ratio transformer and the



(A) MINIMUM FLUX LINKAGE

(B) MAXIMUM FLUX LINKAGE

(C) MAXIMUM FLUX LINKAGE
ROTOR DISPLACED 180°
FROM (B) ABOVE

Figure 5–8.—Induced voltage in synchro control transformer rotor.

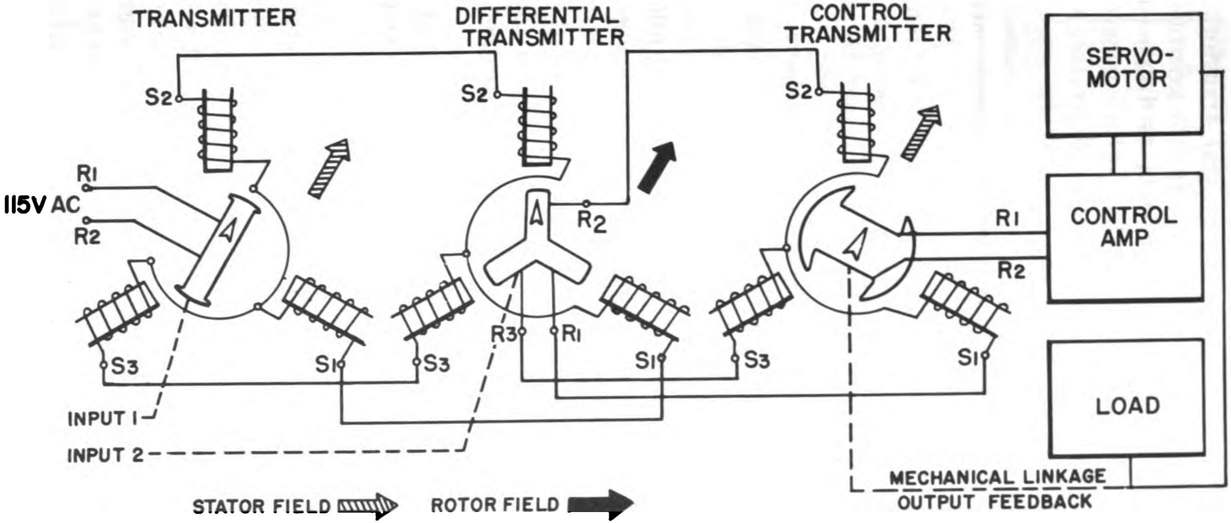


Figure 5–9.—Synchro differential generator used for additional input.

voltages applied to the synchro control transformer are the same as the voltages from the synchro generator. If the synchro differential generator rotor is displaced by a second input, the voltages from the synchro generator to the control transformer will be modified by the synchro differential generator by the amount and direction of its rotor displacement. Thus, the two inputs are algebraically added and fed to the synchro control transformer as a single input.

Magnetic error detectors are not limited to E transformers and synchro devices as other types may be encountered in equipments where special requirements must be met.

Multiple-Speed Data Transmission Systems

The static accuracy of a servomechanism is frequently limited only by the accuracy of the data transmission system. The accuracy of the data transmission system may be increased considerably by employing a multiple-speed data transmission system along with the single-speed system. The error-detector elements of the multiple-speed transmission system rotate at some multiple of the shaft being controlled, while the elements of the single-speed transmission system operate one to one with respect to the controlled shaft.

The schematic diagram of a multiple- and single-speed system is shown in figure 5–10. If the input shaft turns through 1 degree in this example, the single-speed synchro transmitter also is rotated 1 degree while the multiple-speed unit is rotated 10 degrees. The synchro control transformer associated with each of these transmitters is geared in similar ratios with respect to the servo output shaft. A 1-degree error between the position of the input and output shafts therefore produces a relative rotor displacement of 1 degree in the single-speed synchros and 10 degrees in the multiple-speed synchros. If the relation between the rotor displacement and output voltage is linear, the error signal from the multiple-speed system is 10 times that from the single-speed system. This amplification of the

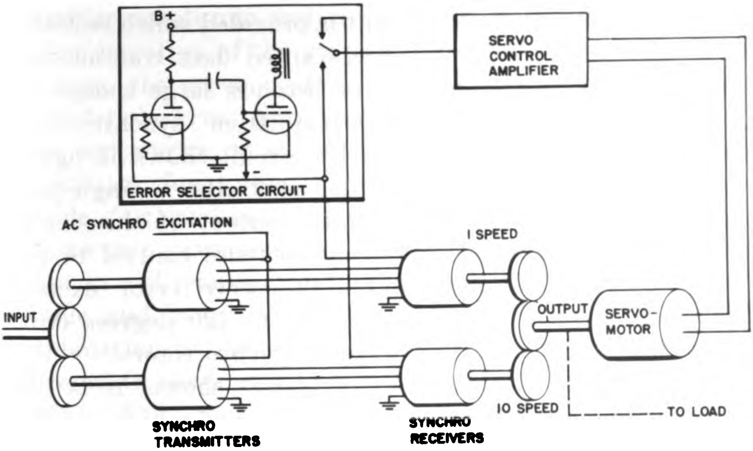


Figure 5–10.—Multiple-speed data transmission system.

error signal in the data transmission link reduces the signal amplification required in the servo controller. If the synchro has an inherent error of 0.1 degree with respect to its own shaft, the consequent servo error introduced by a single-speed data transmission system will be of corresponding magnitude, but the consequent servo error introduced by a 10-speed data transmission system will be only one tenth as great, or 0.01 degree.

A disadvantage of using a multiple-speed error detector lies in the possibility of the system falling out of step and synchronizing in a position differing from the correct position by an integral number of revolutions of the multiple-speed synchro. In the example shown in figure 5–10, if the output shaft were held fixed and the input shaft rotated 36 degrees, the 10-speed synchro transmitter would turn through one complete revolution. At this point the error signal from the multiple-speed error detector would be zero. If the output shaft were then released, the system would operate in a stable fashion with a 36-degree error between the input and output shafts. The purpose of using a single-speed error detector along with the multiple-speed detector is to prevent this ambiguous synchronization.

An error signal selector circuit is provided which switches control of the servo to the single-speed data transmission system whenever the servo error becomes large enough to permit the multiple-speed system from synchronizing falsely. The type of error-selector circuit shown in figure 5–10 is frequently used. It is essentially a single-pole double-throw relay actuated by the output of the single-speed error detector. This relay switches control to the single-speed synchros whenever the servo error exceeds about 12 degrees, which corresponds to 120 degrees error displacement of the multiple-speed synchro rotors.

With the error signal selector circuit shown, it is still possible to have a single ambiguous synchronizing point in the system because the multiple-speed synchros operate on an even multiple of the single-speed synchros. This ambiguous synchronization can occur when the servo input and output shafts are 180 degrees out of phase. In this position both the single-speed and the multiple-speed synchro systems are at null voltage positions and control of the system is retained by the multiple-speed units. One way of eliminating this false synchronization position is by operating the multiple-speed synchros at an odd multiple of the single-speed synchros. While the 180-degree null position of the single-speed synchros still coincides with the null voltage position of the multiple-speed synchros, the corresponding servo position is an unstable one and the servo will not remain at this point.

The disadvantage of using multiple-speed error detectors is the need of an additional synchro system and switching circuit if false synchronization is to be avoided. The increased servo accuracy resulting from the amplification of the error signal and the effective reduction of inherent synchro errors, however, account for the wide use of these multiple-speed data transmission systems.

SERVO CONTROL AMPLIFIERS

In figure 5–5 the output of the error detector (error voltage) is fed to the servo control amplifier. This signal is small in amplitude and requires sufficient amplification to allow actuation of the prime mover. In addition to amplification, the servo control amplifier must, in some cases, transfer the error signal into suitable form for controlling the servomotor or output member. It may also include provisions for special characteristics necessary to obtain stable, fast, and accurate operation.

GENERAL AMPLIFIER CONSIDERATIONS.—Servo amplifiers used in airborne fire control equipment are limited to electronic and magnetic type amplifiers. The operation and explanation of electronic amplifiers and their circuits are covered in chapters 4 and 5 of *Basic Electronics*, NavPers 10087. It is suggested that the reader review these chapters before completing this subject.

In addition to the requirements of basic amplifiers, servo amplifiers must also meet certain additional requirements as follows:

1. A flat gain vs. frequency response for a frequency well beyond the frequency range used.
2. A minimum of phase shift with a change in level of input signal. (Zero phase shift desired but a small amount can be tolerated if constant.)
3. A low output impedance.
4. A low noise level.

Servo amplifiers may utilize either a-c or d-c amplifiers or in some instances a combination of the two. However, the application of d-c amplifiers is limited by such problems as drift and provisions for special bias voltages needed in cascaded stages. Drift, a variation in output voltage with no change in input voltage, can be caused by a change in supply voltage or a variation in value of a component. Consequently, most servo amplifiers utilize a-c amplifiers for voltage amplification. Amplifiers will be discussed further in conjunction with other circuits later in the chapter.

Modulators

As pointed out previously, a-c amplifiers are more satisfactory for amplifying the error signal. However, some airborne fire control equipments utilize a d-c voltage for an error signal. The d-c error voltage may be changed to an a-c signal by the use of a modulator. Modulator circuits used in servo control amplifiers must be phase sensitive and produce an a-c output signal that is proportional to the d-c input signal in amplitude and the phase of it indicative of the polarity.

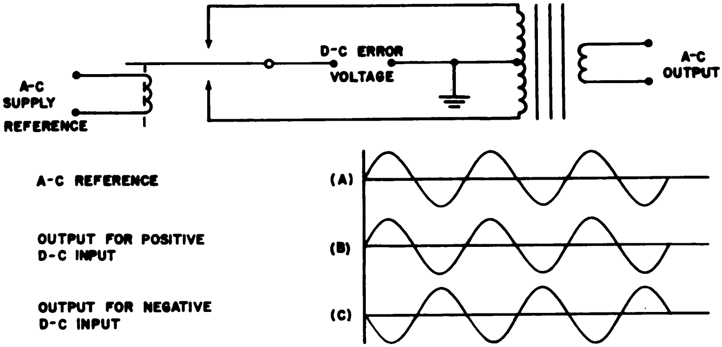


Figure 5–11.—Vibrator modulator.

Vibrator modulators.—A modulator may be either an electromechanical vibrator or an electronic circuit. An example of a vibrator is shown in figure 5–11. An a-c supply voltage is employed to vibrate the contacts of the vibrator in synchronism with the supply voltage. The d-c error voltage is applied to the center contact of the vibrator. Assume that the reference voltage will cause the center arm to contact point A during the first half cycle and point B during the second half cycle. The output is represented by waveform B if the error voltage is positive and by waveform C when the error voltage is negative.

Electronic modulator.—An example of an electronic modulator circuit is shown in figure 5–12. The input d-c error voltage is impressed between E_1 and ground. The a-c reference voltage along with the action of V_1, V_2, R_2, and R_3 effectively clamp the output E_2 at zero potential for one-half cycle of the reference voltage. To accomplish this, the following conditions must exist:

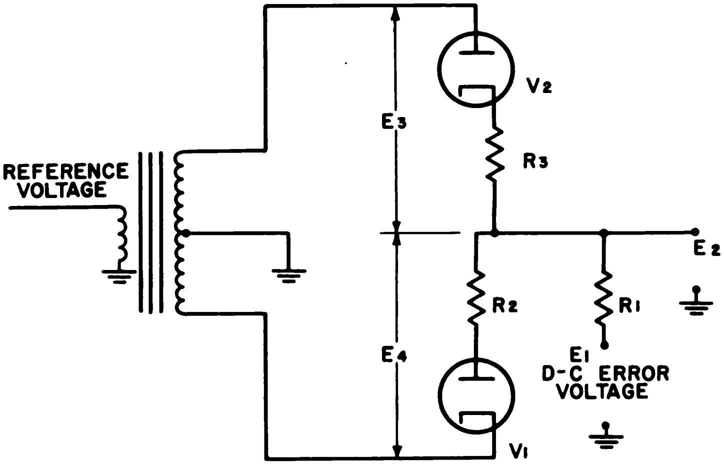


Figure 5–12.—Electronic modulator.

1. R_1 must be much larger than R_2.
2. R_2 and R_3 are equal.
3. V_1 and V_2 must be matched.

With no reference voltage applied, the output E_2 will be the same as E_1, the error voltage. With a reference voltage applied, making the plate of V_2 positive and the cathode of V_1 negative, current will flow through V_1, R_2, R_3, and V_2. Since $R_2 = R_3$, the voltage E_3 will equal E_4. This will effectively clamp the voltage at the junction of R_2 and R_3 at ground potential giving a zero output at E_2. On the reverse half cycle V_1 and V_2 will be nonconducting with E_2 equaling E_1. This will result in an a-c output whose amplitude is determined by the amplitude of the d-c error signal and whose phase is determined by the polarity of the error voltage.

The examples shown above are representative of those used in aviation fire control equipment. You may encounter variations of these circuits. However, they all perform the same function with only slight differences in their operating principles.

Phase Detectors (Demodulators)

In the preceding section of this chapter, it has been stated that the a-c amplifier has inherent advantages over the d-c amplifier, that a d-c error voltage can be changed into an a-c signal, and the a-c signal can be amplified and applied to an a-c servomotor. However, some equipments utilize d-c servomotors which necessitates converting the a-c signal to d.c. To accomplish this, a phase detector, sometimes referred to as a demodulator, is used.

Diode phase detectors.—A typical diode phase detector is shown in figure 5–13. As illustrated, an a-c excitation voltage serves as the reference voltage to the detector. This voltage must come from the same source that is supplying a-c excitation to the synchro system, or whatever type of error detector that is being employed, and must be in phase with the excitation voltage. This permits a phase comparison of the error voltage with the reference voltage. The plates of the two diodes are supplied with this reference voltage in such a manner that the two plates will be in phase. Assuming that there is no error signal from T_2 to the plates of the diodes at the time the plates are on a positive half cycle, the two diodes will conduct equally. The voltages produced across R_1 and R_2 are equal, making

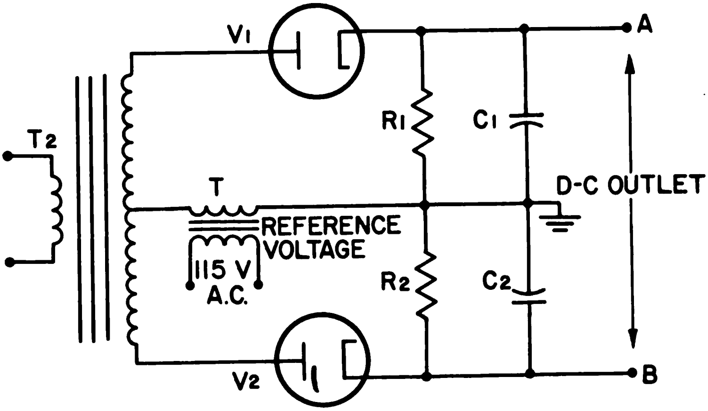


Figure 5–13.—Diode phase detector.

the cathode of V_1 and V_2 at equal potential with respect to ground. With the two output terminals at the same potential, the output voltage will remain at zero as long as there is no error signal applied.

If an error signal is applied to T_2 making the plate of V_1 positive at the same instant the reference voltage on the plates of V_1 and V_2 is on its positive half cycle, V_1's conduction will be increased over the no signal condition. Since the voltages applied to the plates are both alternating, the voltage developed across R_1, and R_2 would also be alternating. However, R_1C_1 and R_2C_2 form a long time constant to the input frequency and filter most of the ripple, giving a d-c output.

If the error signal applied to T_2 is changed by 180 degrees, V_2 would now increase its conduction while the conduction of V_1 would be reduced. This would result in an output voltage of reversed polarity. Variations of the diode phase detector may be encountered; however, their principle of operation is essentially unchanged.

TRIODE PHASE DETECTORS.—A phase detector using triode tubes is shown in figure 5–14. This circuit also provides amplification of the error signal in addition to phase detection. In this circuit, as in the previous one, the plates

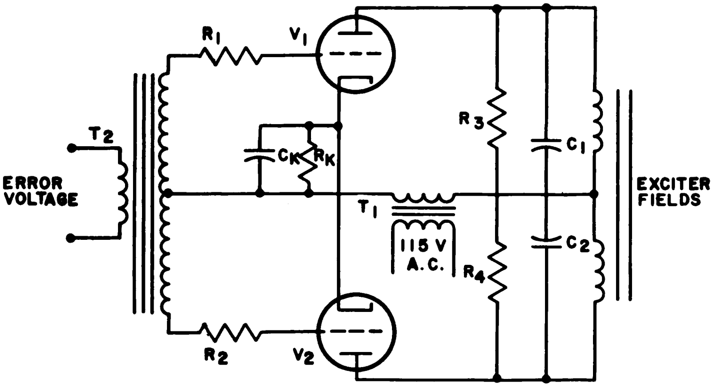


Figure 5–14.—Triode phase detector.

of the tubes are supplied with the a-c reference voltage in such a manner that the plates will be in phase. For the purpose of explanation, assume that no error signal is present at T_2. When the plates of V_1 and V_2 are positive, the two tubes will conduct equally. The plate current that flows will set up magnetic fields in the d-c motor exciter windings that will be equal and opposite; therefore, the fields will cancel and produce no output. When the plate voltages are on a negative half cycle, C_1 and C_2 will be discharging through their respective exciter windings to maintain a constant d-c current through the windings.

If an error signal is introduced into the primary of T_2 with a phase relationship that causes the grid of V_1 to be positive at the same instant that the plate of V_1 is positive, the following conditions will exist:

1. On this half cycle the conduction of V_1 will be increased above its no error signal condition.
2. The heavier plate current will cause a stronger field to be created in the upper exciter winding.
3. At this same instant, since the grid of V_2 is on a negative half cycle, its average conduction will be reduced to a level below that of its no error signal condition.
4. The lower level of plate current will cause a weaker field to be produced in the lower exciter winding.
5. Since the magnetic fields produced in the exciter windings are no longer of equal amplitude, they can no longer cancel each other.
6. The exciter will produce an output voltage of a polarity controlled by the polarity of the resultant field and of an amplitude controlled by the relative strength of this resultant field.
7. The exciter output will cause the proper mechanical actions necessary to reduce the amplitude of the error to zero.
8. As the error signal is reduced to zero, the current conduction through V_1 and V_2 will again be balanced. Also the exciter fields will be equal and opposite, canceling each other, reducing the exciter output to zero, and stopping

the mechanical action. Resistors R_1 and R_2 prevent excessive grid current when the error angle is large.

Special Servo Amplifier Circuits

You have been shown how a servo control amplifier may have provisions for changing a d-c error signal to an a-c signal and how an a-c error signal may be detected to supply a d-c voltage to a servomotor or controller. In order that you as an AQ2 will be familiar with other circuits that you will encounter, other special amplifier circuits will be discussed.

THE TWO-STAGE D-C SERVO CONTROL AMPLIFIER.—If somewhat more power is required by the servomotor than can be supplied by the servo amplifier (fig. 5–14), a push-pull d-c amplifier can be inserted between the phase-sensitive triodes and the servomotor. In the schematic diagram (fig. 5–15), the output of the phase detector triodes is now taken across the parallel R–C networks in the plate circuit.

The bias source, E_{cc}, for the d-c amplifier is connected with its positive terminal on the grid side. This positive voltage will subtract from the highly negative voltage across the capacitor to give a resulting negative voltage which will allow the tube to operate on the linear portion of its characteristic curve.

Where there is no signal input from the error detector, the plate currents of the phase-sensitive rectifiers are equal. The outputs of V_1 and V_2 are applied to the grids of V_3 and V_4, respectively. Equal output from V_1 and V_2 will cause equal currents to flow in V_3 and V_4. With R_5 and R_6 equal in resistance and current, the voltage across the motor is zero. Consequently, the motor does not turn.

When there is a signal output from the error detector, the following action occurs. Assume that the error signal makes the grid of V_1 positive and the grid of V_2 negative. The plate current of V_1 increases and the plate current of V_2 decreases. An increasing plate current in V_1 increases the charge on capacitor C_1 and conversely a decreasing plate current in V_2 decreases the charge on capacitor C_2.

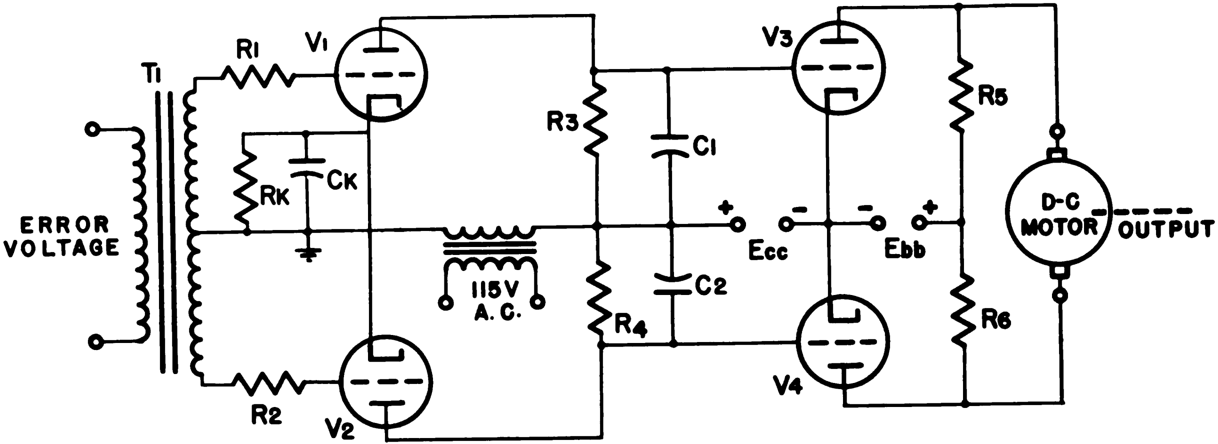


Figure 5–15.—Two-stage d-c servo control amplifier.

As a result of this change in error signal, the voltage on the grid of V_3 is now more negative than the voltage on the grid of V_4. This increased negative voltage on the grid of V_3 decreases its plate current and the voltage e_3 decreases. The decreased negative voltage or the grid of V_4 increases its plate current and the voltage e_4 increases. As a result, a voltage difference appears across the motor armature and the motor rotates.

When the output signal from the error detector reverses in phase, the sequence of events that follow will cause the motor to reverse its direction of rotation.

MAGNETIC AMPLIFIERS USED AS SERVO CONTROL AMPLIFIERS.—A somewhat different type of servo amplifier used in aviation fire control equipment is the magnetic amplifier. Since magnetic amplifiers were discussed in detail in the previous chapter of this course, only their application as servo amplifiers will be covered.

The servomotor used in conjunction with the magnetic amplifier shown in figure 5–16 is an a-c type. The uncontrolled phase may be connected in parallel with transformer T_1 by utilizing a phase shifting capacitor, or it may

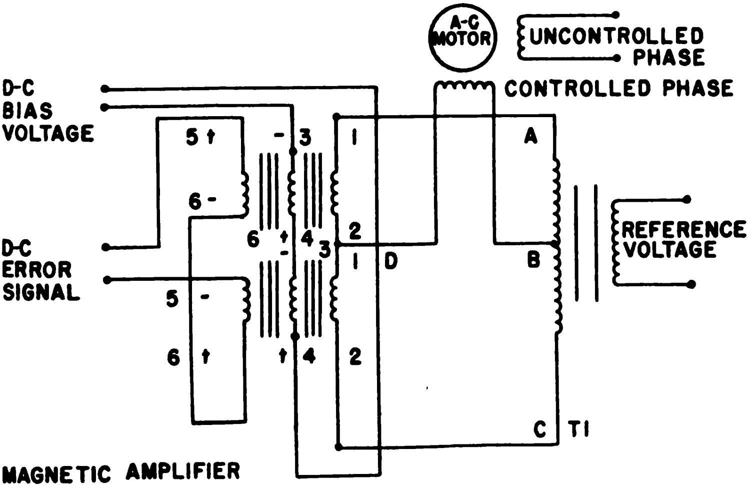


Figure 5–16.—Magnetic amplifier servo control amplifier.

be connected to a different phase of a multiphase system. The controlled phase is energized by the magnetic amplifier and its phase relationship is determined by the polarity of the d-c error voltage.

The magnetic amplifier consists of a transformer (T_1) and two saturable reactors, each having three windings. It will be noted that the d-c bias current flows through a winding of each reactor and the windings are connected in series-aiding. This bias current is supplied by a d-c bias power source. A d-c error current also flows through a winding in each reactor, however, these windings are connected in series-opposing.

The reactors Z_1 and Z_2 are equally and partially saturated by the d-c bias current when no d-c error signal is applied. The reactance of Z_1 and Z_2 are now equal resulting in points B and D being at equal potential. There is no current flow through the controlled phase winding.

If an error signal is applied causing the current to further saturate Z_2, the reactance of its a-c winding is decreased. This current through Z_1 will tend to cancel the effect of the d-c bias current and increase the reactance of its a-c winding. Within the operating limits of the circuit, the change in reactance is proportional to the amplitude of the error signal. Hence, point D is now effectively connected to point C causing motor rotation. Reversing the polarity of the error signal will cause the direction of rotation to reverse.

The basic magnetic servo amplifier discussed above has a response of approximately 6 to 20 cycles. In some applications this delay would be excessive, creating too much error. However, this delay can be reduced to about one cycle by using special push-pull circuits.

OUTPUT MEMBERS

The output of the servo control amplifier is fed to an output member. The functions of this member, usually a servomotor, are to supply torque, power and dynamic characteristics required to position the servo load. Ideally, the power device should require small power from the control amplifier, accelerate rapidly, be of small size and weight, long life, small time lags, and an adequate speed range. In aviation fire control systems, the electric motor is most frequently used as an output member. However, electromagnetic clutches, hydraulic devices, and pneumatic devices are also used.

Electric Motors

In aviation fire control equipment, electric motors are primarily used to drive the servo load. The type of electric motor used within a particular equipment is determined by such factors as type of power available, output power, speed range, inertia, and electrical noise.

ALTERNATING-CURRENT MOTORS.—Alternating-current motors are frequently used in low power servo applications because of their simplicity, reliability, absence of commutator sparking, and rapid response. However, they have a disadvantage of having a narrow speed range characteristic. The theory of operation of a-c motors is discussed in chapter 15 of *Basic Electricity*, NavPers 10086. This course will briefly discuss the types of motors applicable to servo systems.

The TWO-PHASE INDUCTION MOTOR is the most widely used a-c servomotor. The stator of the motor consists of two similar windings which are positioned at right angles to each other. The rotor may be wound with short-circuited turns of wire or it may be a squirrel cage rotor. The squirrel cage rotor is most common and is made up of heavy conducting bars which are set into armature slots, the bars being shorted by conducting rings at the ends.

Two a-c voltages 90 degrees out of phase must be applied to the stator windings in order for the motor to turn. These out-of-phase voltages generate a rotating magnetic field which induces a voltage in the rotor. This induced voltage generates a magnetic field in the rotor that is displaced 90 degrees from the stator magnetic field. The interaction of these two magnetic fields causes the armature to rotate.

As stated previously, the voltage to the two stator windings must be 90 degrees out of phase to cause the rotor to turn. The direction of rotation is determined by the phase relationship of the stator windings which, in turn, is determined by the servo error detector. One phase is connected directly to one of the stator windings while the other phase is used to energize an error detector. The resulting error voltage will either be in phase or 180 degrees out of phase with the signal applied to the error detector. This will cause the controlled phase to either lead or lag the uncontrolled phase by 90 degrees.

Most induction motors have low starting torque and high torque at high speed. For servo applications, it is desirable to have high starting torque in order that the system may have a low time lag. This may be accomplished by increasing the armature resistance with the use of materials such as zinc for the conducting bars. This increased torque at low speed results in decreased torque at high speed. However, increased stability of the servo system is a desirable result of this change.

SPLIT-PHASE A-C MOTORS are similar to the two-phase induction motor. It differs only in that a phase shifting network is used to shift the phase of the voltage supplied to one of the windings by 90 degrees. This is usually accomplished by connecting a capacitor in series with the uncontrolled winding of the stator. Direction of rotation and reversal is accomplished in the same manner as in the two-phase motor discussed above.

Other types of motors that may be used with an a-c power supply are **SHADED POLE**, **UNIVERSAL**, and **REPULSION** motors. They utilize various methods of obtaining rotation reversal. However, they are seldom found in fire control equipments.

DIRECT-CURRENT MOTORS.—Direct current motors have an advantage of having higher starting torque, reversing torque, and less weight for equal power than a-c motors.

SERIES MOTORS are characterized by their high starting torque and poor speed regulation with a change in torque. Higher torque can be obtained on reversal of direction with a series motor than any other type. However, it is a unidirectional motor and requires special switching circuits to obtain bidirectional characteristics. This is normally done by switching the armature or field connections but not both.

A variation of the series motor that has bidirectional characteristics is the SPLIT-SERIES MOTOR. The motor has two field windings on its frame, only one of which is used for each direction of rotation. This reduces the number of relay contacts required for reversing by one-half. This double winding also reduces the torque capabilities of the motor as compared to a straight-series motor wound on the same frame.

The most frequently used d-c servomotor is the SHUNT MOTOR. Its direction of motion is controlled by varying the direction of flow of either the armature or field current. The uncontrolled current is usually maintained constant to preserve a linear relationship between the motor output torque and the voltage or current input. The field windings are usually two differentially wound coils to facilitate direction control of the field current by the servo control amplifier. The field current is usually controlled with receiving type vacuum tubes. The larger armature currents require thyratrons or generators as current regulators but are not normally found in aviation fire control systems.

Magnetic Clutches

Any device utilizing an electrical signal that may be used to control the coupling of torque from an input shaft to an output shaft is a MAGNETIC CLUTCH. This coupling may be accomplished by the contact between friction surfaces or by the action of one or more magnetic fields. A magnetic clutch is used only to couple the input torque to the output shaft. Thus, it is capable of controlling large amounts of power and torque for its size and weight. The magnetic clutch may be used with a large flywheel driven at high speed by a small motor. The flywheel may be able to impart very large acceleration to the load when the magnetic clutch is energized.

There are two distinct types of magnetic clutches. Some transmit torque by physical contact of frictional surfaces. Others utilize the action of magnetic flux produced by two sets of coils or one set of coils and induced eddy currents resulting from rotating the one set of coils near a conducting surface. The eddy current type of clutch offers smoother operation and has no problem of wear due to friction. Both types have suitable control characteristics and are found in servomechanisms.

Hydraulic Devices

Hydraulic components used in servomechanisms are frequently found in aviation fire control equipments. Hydraulic power devices, such as motors and associated control valves, have an advantage of a response much faster than the best electric motors and equal to that of a magnetic clutch system. They also require a minimum of maintenance, have very high accuracy, and are well adapted to loads such as aviation gun turrets.

The essential components of a hydraulic system are:

1. Source of high pressure oil and sump to receive discharged oil.
2. Control valve and means of employing an actuating signal.
3. Actuator (motor or cylinder).

The theory of operation of a hydraulic system is discussed in chapter 7 and 12 of *Basic Hydraulics*, NavPers 16193.

The source of high pressure oil serves as a source of power to operate the actuator. However, this source of power is controlled by the control valve. This valve is actuated by the output from the servo control amplifier. This control is normally accomplished by feeding the error signal to a solenoid controlled valve. However, the error signal could be used to drive an electric motor which, in turn, actuates the control valve. The actuator is usually in the form of an axial motor which must be a reversible and variable speed type. Some applications may employ a cylinder where linear motion is required for positioning.

SERVOMECHANISM OSCILLATION

In aviation armament control systems, servomechanisms are utilized for various functions and must meet certain performance requirements. These requirements not only concern such things as speed of response and accuracy, but the manner in which the system responds in carrying out its command function. All systems will contain certain errors, the problem being to keep them within the allowable limits.

As discussed previously, the servomotor must be capable of developing sufficient torque and power to position the load in a minimum of time. The servomotor and its connected load will have sufficient inertia to drive the load past the point of command position. This overshooting will result in an opposite error voltage, reversing the direction of rotation of the servomotor and the load. The servomotor will again attempt to correct the error and again overshoot the point of correspondence with each reversal requiring less correction until the system is in correspondence. The time required for the oscillations to die out will determine the transient response of the system and can be greatly reduced by the use of damping.

Types of Damping

VISCOUS DAMPING.—The function of damping is to reduce the amplitude and duration of the oscillations that may exist in the system. The simplest form of damping is VISCOUS DAMPING. Viscous damping is the application of friction to the output load or shaft that is proportional to the output velocity. The amount of friction applied to the system is critical and will materially affect the results of the system. When just enough friction to prevent overshoot is applied, the system is said to be CRITICALLY DAMPED.

When the friction is greater than that for critical damping, the system is OVERDAMPED. However, when damping is slightly less than critical, the system is said to be slightly UNDERDAMPED, which is usually the desired condition. The application of friction absorbs power from the motor and is dissipated in the form of heat.

A pure viscous damper would absorb an excessive amount of power from the system. However, a system having some of the characteristics of a viscous damper with somewhat less power loss is used in actual practice. The first of this type of damper to be discussed utilizes a dry friction clutch to couple a weighted flywheel to the output drive shaft. A flywheel has the property of inertia which may be defined as that property of matter by which it will remain at rest or in uniform motion in the same straight line or direction unless acted upon by some external force.

However, since the flywheel is coupled to the output shaft with a friction clutch, any rapid change in velocity of the output member will cause the clutch to slip. This slipping effectively disconnects the flywheel instantaneously but allows sufficient power to be coupled to the flywheel to overcome its inertia. As the inertia is gradually overcome, the flywheel gains speed and approaches the velocity of the output member. As the point of correspondence is neared and the error signal is reduced, the inertia of the flywheel gives up power to the system, causing the load to increase its overshoot. When the system attempts to correct for this overshoot, the inertia of the flywheel will add to the output load, reducing the effect of the correcting signal. This effect dampens the oscillations in the system, reducing its transit time.

Another type of damper used is the EDDY CURRENT damper. This damper utilizes the interaction of induced eddy currents and a permanent magnet field to couple the output shaft to a weighted flywheel.

The effect of damping is shown in figure 5–17. The solid line shows the action of the load without damping. The time required to reach a steady-state condition without

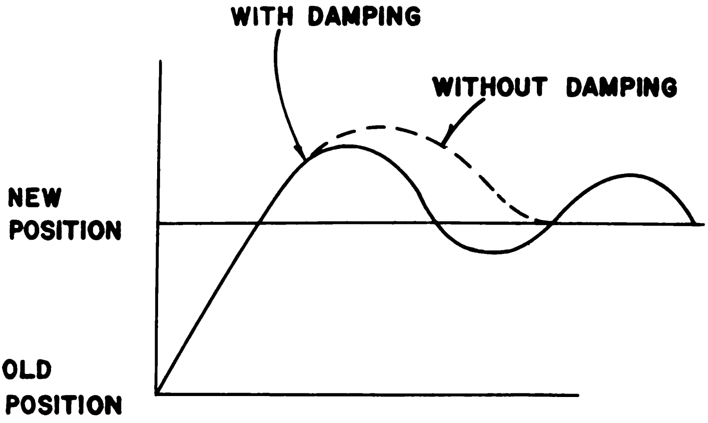


Figure 5–17.—Effect of friction damper.

damping should be noted. This time is greatly reduced although the initial overshoot is increased.

As shown in figure 5–17, viscous dampers effectively reduced transient oscillations, but it also produced an undesired steady-state error (velocity lag or position error). Since the friction damper absorbs power from the system, its use is normally limited to small servomechanisms.

Error-rate damping.—To overcome the disadvantages of the viscous dampers and still provide damping, error-rate damping is used. This type of damping consists of introducing a voltage that is proportional to the rate of change of the error signal. This voltage is fed to the servo control amplifier and combined with the error signal. Figure 5–18 shows the effect of error-rate damping on the torque output of the servomotor. Curve A shows the torque resulting from the error voltage; curve B shows the torque resulting from the error-rate damper; and curve C is the resultant of curves A and B. It should be noted that torque resulting from the damper increases the total torque as long as the error component is increasing. Once the error component starts to decrease, the error-rate damper produces a torque in an opposite direction reducing the transit time of the system.

There are two methods of generating an error-rate voltage normally found in aviation fire control equipments. They are the TACHOMETER and ELECTRICAL NETWORKS. The tachometer error-rate damper utilizes a device which is essentially a generator having an output voltage proportional to its shaft speed. The tachometer is connected to the shaft of the output member giving a voltage proportional to its speed. The output voltage is fed to a network that modifies this voltage so that it is proportional to a CHANGE in input voltage. This voltage is fed back to the servo control amplifier and added with the error signal as shown in figure 5–18.

Electrical networks used for error-rate damping consist of a combination of resistors and capacitors used to form an R–C differentiating network. For a detailed explanation of R–C circuits, refer to *Basic Electricity*, NavPers 10086, pages 234–240 and 413–418. These networks, sometimes referred to as phase advance or lead networks, vary in design, depending on the type of error signal. However, in practice, networks are normally limited to the d-c type.

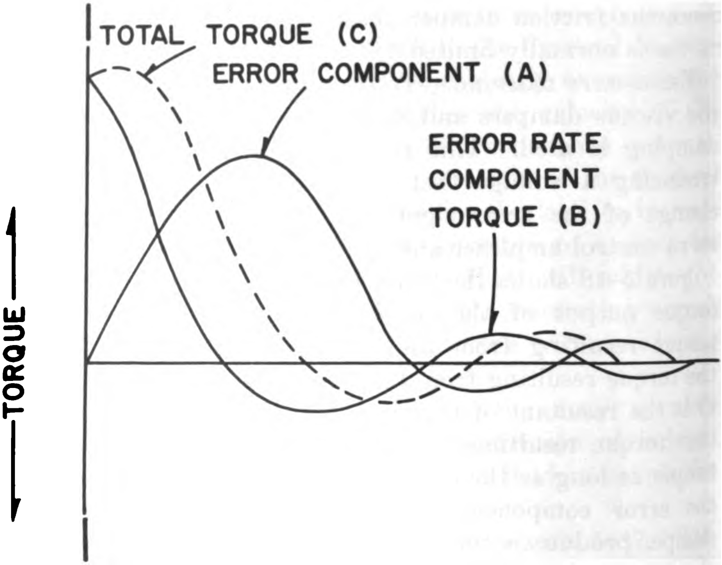


Figure 5–18.—Torque variations using error-rate damping.

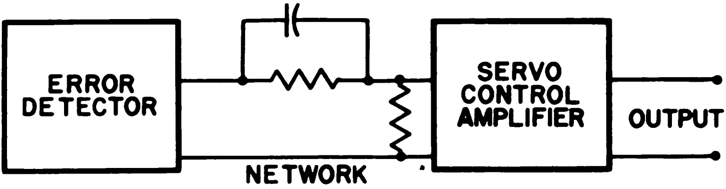


Figure 5–19.—Error-rate stabilization network.

(See fig. 5–19.) This is because of the unstable results that would be caused by a small change in frequency of the power source. An a-c system may utilize a d-c network by first using a demodulator (detector) prior to the network. However, the output of the network must be modulated for use in the remainder of the a-c system. Like the tachometer, the output of the network is fed to the servo control amplifier.

Integral Control

Servomechanisms used in aviation fire control are sometimes required to follow an input function, the magnitude of which changes at a constant rate with time, such as a turret system tracking a target. Thus, if the input is the angle of a shaft, the velocity of the shaft may be constant for a substantial percentage of time. The servomechanism may be required to respond to this type of input with substantially zero error. The error that characterizes the servo response to a constant velocity input is known as the VELOCITY ERROR.

To correct for velocity error or an inaccuracy due to a steady-state error, an INTEGRAL CONTROL may be used. This control modifies the error voltage in such a manner that the signal fed to the servo control amplifier is a function of both the amplitude and time duration of the error signal. This is accomplished by the use of a variable voltage divider whose output would increase with time for a constant input. As in all voltage dividers, the output is only a portion of the input which effectively reduces the amplitude of the error signal. To compensate for this loss of amplitude, additional amplification must be used

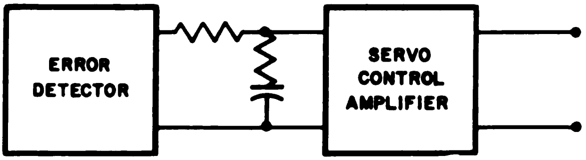


Figure 5–20.—Integral stabilization network.

either in the form of a preamplifier or a higher gain servo control amplifier. With the overall gain of the system now increased to give a normal output for transient error signals, small velocity or steady-state error signals of long duration will result in somewhat increased output to the servomotor due to the action of the integral control.

The integral control, shown in figure 5–20, consists of a combination of resistors and capacitors connected to make an integrator circuit for a d-c error signal. The size of the components are such that the capacitor will not have sufficient time to change with fluctuations in error voltage. Only that portion of the transient error signal developed across R_1 will be impressed on the amplifier. However, with a velocity error or steady-state error of longer duration, the capacitor C_1 will charge, increasing the amplitude of the amplifier input.

Networks shown in figure 5–20 are not limited to d-c systems as a demodulator may be used prior to the integrator and its output modulated for easier amplification.

Gain, Phase, and Balance

EFFECT OF CONTROLLER GAIN ON SYSTEM OPERATION.—The overall system gain has a most important effect on the servomechanism response characteristics and is one of the more easily adjustable parameters in electronics servo controllers. Increasing the system gain reduces the system velocity errors and those steady-state errors resulting from restraining torques on the servo load or misalinement in the system. An increase in system gain also increases the speed of response to transient inputs. However, excessive gain always decreases the rate at which oscillatory transients disappear, and continued increase in the system gain eventually produces instability.

PHASE AND BALANCE ADJUSTMENTS.—Servo systems using push-pull amplifiers must be balanced to insure equal torque in both directions of the servomotor. This adjustment should be checked periodically as a change in value of a component may cause an unbalanced output.

A phase control is included in some servo systems using a-c motors. The two windings of the a-c servomotor must be energized by a-c signals that are 90 degrees apart. A phasing adjustment is normally included in the system to compensate for any phase shift in the amplifier circuit resulting in unstable operation of the system. This adjustment may be located in the control amplifier, or in the case of a split-phase motor, it may be in the uncontrolled winding.

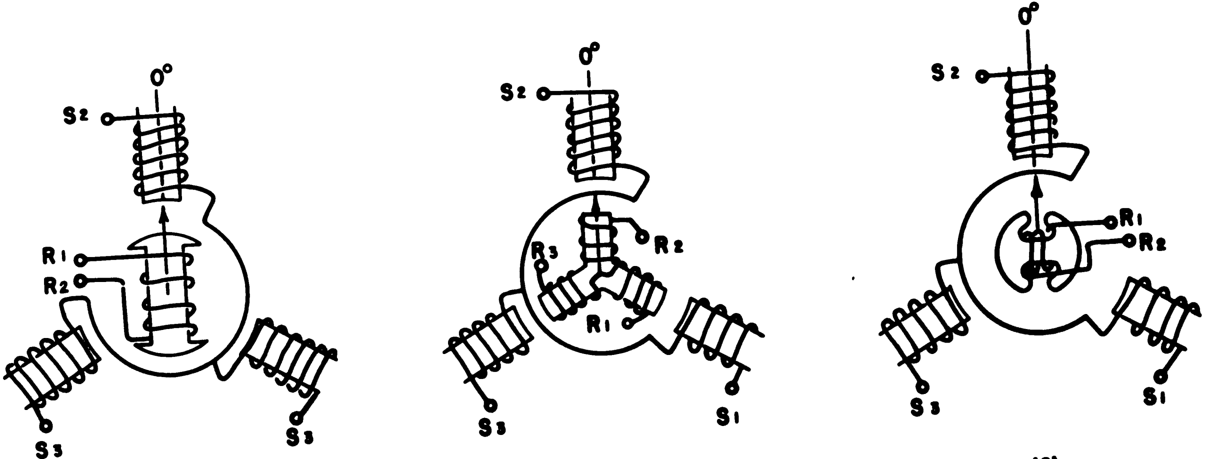
ZEROING SYNCHRO UNITS

In this chapter we have stressed the importance of accuracy of servomechanisms. In any servomechanism utilizing synchro units, it is highly important that the units be electrically zeroed.

Transmitters and Receivers

Before discussing the methods used in zeroing synchro transmitters and receivers, it is necessary to review the meaning of electrical zero. For a synchro transmitter or receiver to be in a position of electrical zero, the rotor must be alined with S_2, the voltage between S_1 and S_3, as shown in figure 5–21 (A), must be zero, and the phase of the voltage at S_2 must be the same as the phase of the voltage at R_1.

The most common methods of zeroing synchro transmitters and receivers are the a-c voltmeter, electrical lock, and temporary jumper. The a-c voltmeter method requires two steps, a coarse and fine adjustment. The coarse ad-

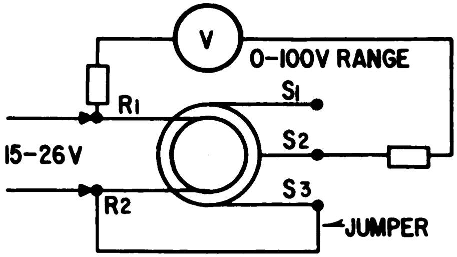


(A)
TRANSMITTER AND RECEIVER

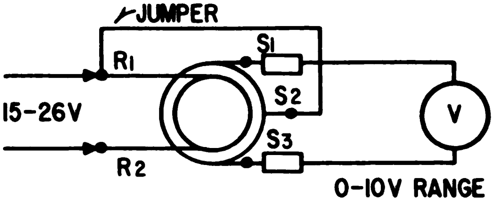
(B)
DIFFERENTIAL
TRANSMITTER AND RECEIVER

(C)
CONTROL TRANSFORMER

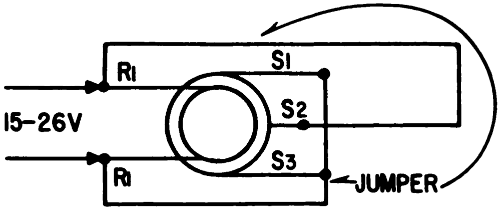
Figure 5-21.—Synchro electrical zero positions.



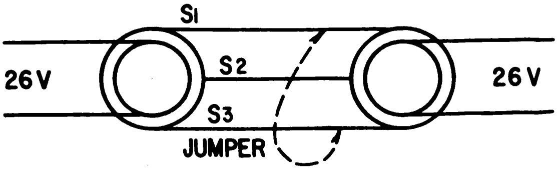
A-C VOLTMETER METHOD
(A) COARSE ADJUSTMENT--
ADJUST ROTOR FOR
MINIMUM



(B) FINE ADJUSTMENT--
ADJUST ROTOR
FOR NULL



(C) ELECTRICAL LOCK METHOD--
ROTOR POSITIONS ITSELF



(D) TEMPORARY JUMPER METHOD

Figure 5-22.—Methods of zeroing synchro transmitters and receivers.

justment alines the rotor to approximate electrical zero and is made by connecting the meter and jumper as shown in figure 5–22 (A). The rotor is rotated until a null is read on the meter. This null should be somewhat less than the supply voltage, and any reading larger than the supply voltage indicates the rotor is approximately 180 degrees from electrical zero. The fine adjustment is made by connecting the meter and jumper (fig. 5–22 (B)) and rotating the rotor a few degrees in both directions, determining the null or zero position. When the zero position has been determined, the rotor should be secured by the mechanical linkage of the system; or if not installed in a system, some means must be provided to lock it in its zero position.

The electrical lock method of zeroing is accomplished by first making the connections as shown in figure 5–23 (C) and applying power to the unit. When this is done, the unit will position itself at electrical zero.

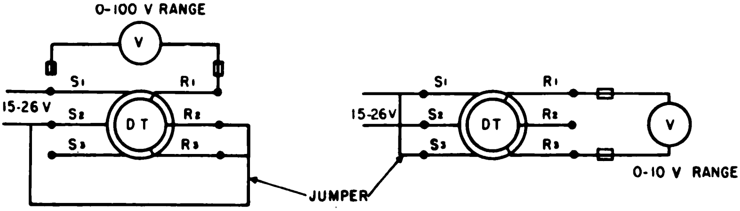
The temporary jumper method is limited in application since it can be used only in a synchro system when the other unit or units have been zeroed previously. When zeroing a receiver, connected it to a transmitter that is set at its electrical zero. (See fig. 5–22 (D).) With the jumper connected and power applied, the receiver will position its rotor at electrical zero. When zeroing a transmitter, the transmitter must be connected to a receiver whose rotor is set to its electrical zero. Assume a position of zero for the transmitter and apply power to the units. Note the number of degrees of rotation of the receiver and correct the transmitter zero position by the same amount in the opposite direction. Disconnect the power and again set the receiver to its electrical zero position. Reapply power and check the transmitter's zero position by repeating the same procedure.

Differential Transmitter

The electrical zero position of a synchro differential transmitter or receiver is when the three windings of the rotor are in correspondence with their respective stator windings and their respective voltages are in phase. (See fig. 5–21 (B).) The two most common methods of zeroing differential transmitters are the a-c voltmeter and temporary jumper. These methods are quite similar to those previously discussed. However, it should be noted that the electrical lock method cannot be used on differentials.

The a-c voltmeter method is illustrated in figure 5–23 (A) and (B). With the unit connected as shown in figure 5–23 (A), rotate the rotor until a minimum or null position is reached. Note: A voltmeter reading in excess of the applied voltage indicates the rotor is approximately 180 degrees from its zero position. Connect the unit as shown in figure 5–23 (B) and with the meter on a low voltage range, rotate the rotor a few degrees in both directions to locate the zero or null position. When the electrical zero position is located, tighten the linkage connecting the differential to the other units of the system. If the unit is not installed in a system, some means must be provided to lock the unit in its zero position.

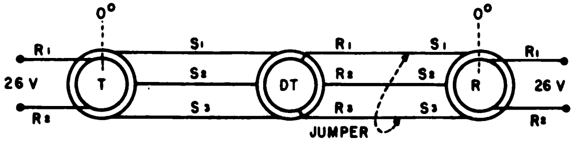
The temporary jumper method is shown in figure 5–23 (C). This method is limited in application since it can



A-C VOLTMETER METHOD

(A) COARSE ADJUSTMENT-- ADJUST ROTOR FOR MINIMUM

(B) FINE ADJUSTMENT-- ADJUST ROTOR FOR NULL



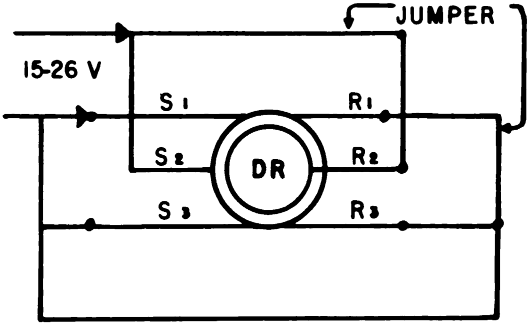
(C) TEMPORARY JUMPER METHOD

Figure 5–23.—Methods of zeroing differential transmitters.

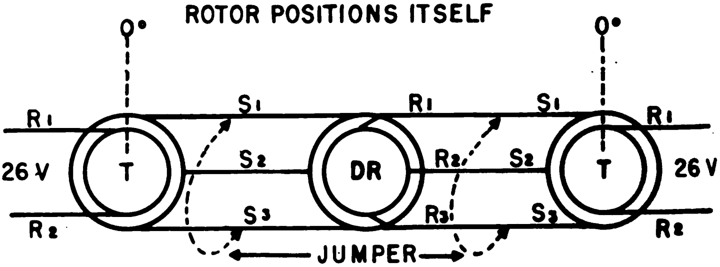
be used only in a synchro system where the other units have already been alined. The synchro transmitter and receiver must be set to electrical zero and the differential transmitter rotor locked in its assumed zero position. After connecting the jumper as shown in figure 5–23 (C), apply power and check the position of the motor shaft. If the motor has rotated from its zero position, remove the power and adjust the differential transmitter by the same amount in the opposite direction. Reapply the power and repeat the procedure until all units remain at their zero setting with the power applied.

Differential Receivers

Electrical zero for a differential receiver is illustrated



(A) ELECTRICAL LOCK METHOD--
ROTOR POSITIONS ITSELF



(B) TEMPORARY JUMPER METHOD--
ROTOR POSITIONS ITSELF

Figure 5–24.—Methods of zeroing differential receivers.

in figure 5–21 (C). The two most common methods of zeroing synchro differential receivers are the ELECTRICAL LOCK and the TEMPORARY JUMPER. The electrical lock method is illustrated in figure 5–24 (A). When necessary connections are made and power is applied, the rotor will position itself to its electrical zero position. The temporary jumper method can be used only when the other components of the system can be locked in their electrical zero position. Connections are made as shown in figure 5–24 (B). When the transmitters are zeroed and power is applied, the rotor of the receiver will position itself at its electrical zero position. Reconnect the rotor shaft while the unit is in its zero position if installed, or some

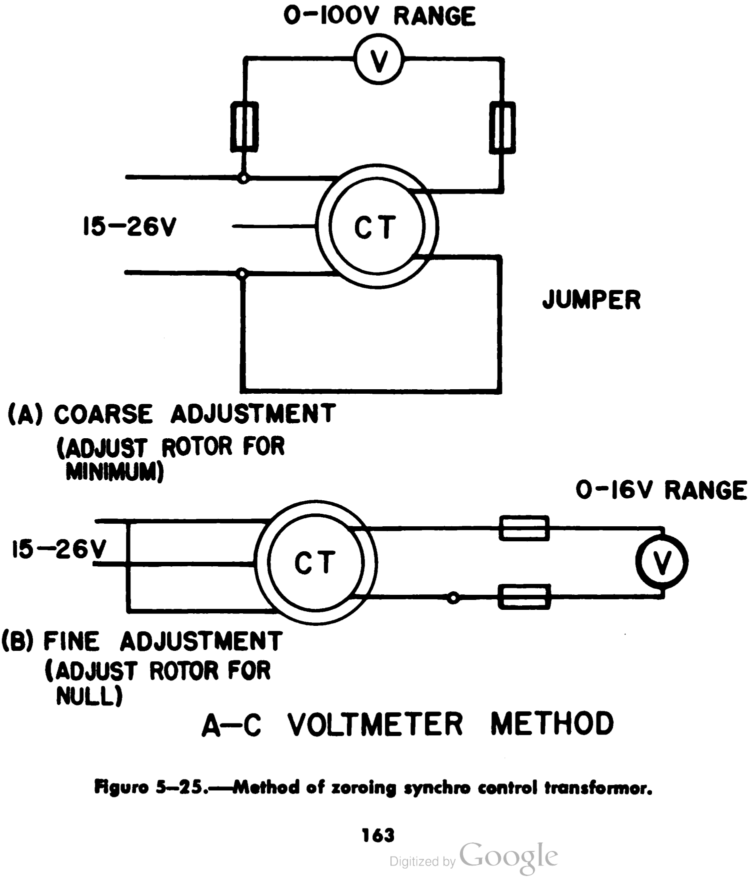

0–100V RANGE
V
15–26V
CT
JUMPER
(A) COARSE ADJUSTMENT (ADJUST ROTOR FOR MINIMUM)
0–16V RANGE
15–26V
CT
V
(B) FINE ADJUSTMENT (ADJUST ROTOR FOR NULL)
A–C VOLTMETER METHOD

Figure 5–25.—Method of zeroing synchro control transformer.

means must be provided for locking the unit in its zero position.

Control Transformers

The synchro control transformer is normally zeroed by using the a-c voltmeter method. It should be remembered that the electrical zero position of the control transformer is 90 degrees from that of a receiver since the rotor winding must be perpendicular to the stator's resulting magnetic field to have a zero output. (See fig. 5–21 (D).) The course adjustment is made by connecting the meter and unit as shown in figure 5–25 (A). The rotor is rotated to give a minimum or null reading on the voltmeter. The final adjustment is made by connecting the unit as shown in figure 5–25 (B) and displacing the rotor a few degrees in both directions to determine the null or electrical zero position. Once the zero position has been determined, the unit must be locked as discussed previously.

QUIZ

1. The direction of rotation of a shunt d-c motor may be controlled by
   a. varying the field current
   b. reversing the direction of either the armature or field current
   c. reversing the direction of both the armature and field current
   d. connecting the field windings in parallel

2. To utilize a-c amplifiers for a d-c error signal, a ________________ circuit would be used.
   a. demodulator
   b. modulator
   c. phase detector
   d. damper

3. The essential components of a servo mechanism are the data transmission system, the servo control amplifier, and the
   a. error signal
   b. correction signal
   c. control transformer
   d. servomotor

4. The biggest disadvantage of potentiometer error detector systems is the
   a. low accuracy of the system
   b. large size of the components
   c. high drive torque required to drive the wiper arms
   d. short life of the system caused by the overheating of the components

5. The stators of a synchro generator consist of three coils which are
   a. 90 degrees apart
   b. 120 degrees apart
   c. 90 electrical degrees apart
   d. 120 electrical degrees apart

6. In multiple-speed data transmission systems shown in figure 5–10, the relay will switch control to the single-speed synchro when the error is approximately
   a. 0.01 degrees
   b. 10 degrees
   c. 12 degrees
   d. 120 degrees

7. In multiple-speed data transmission systems, one way of eliminating false nulls is to operate at
   a. odd multiples
   b. a one-to-one ratio
   c. 1–26 speeds
   d. 1–28 speeds

8. One of the requirements of a servo amplifier is that it has
   a. high output impedance
   b. low output impedance
   c. high phase shift
   d. low gain

9. A servomechanism accomplishes its function by exercising control over the
   a. load directly
   b. differential element
   c. external power source
   d. input error signal

10. The signal input to the amplifying element of a servo system is proportional to the
    a. control signal
    b. difference between the servo input and output
    c. rate of change of control signal
    d. difference between output and reference

11. The most desirable characteristic of a d-c servomotor is its
    a. constant speed characteristic
    b. simplicity and ruggedness
    c. high starting torque
    d. adaptability to bidirectional loops

12. The E transformer error detector is characterized by
    a. fair accuracy and unlimited input motion
    b. excellent accuracy with limited input motion
    c. poor accuracy, limited input motion but rugged
    d. unlimited input motion and high efficiency

13. The synchro control transformer is characterized by
    a. limited motion and mechanical advantage
    b. being high in accuracy and slow in response
    c. its mechanical and electrical null shafts
    d. its unlimited rotation angle

14. Using a one and a twenty-three multiple-speed transmission system having a one-degree error in the one-speed synchro, the error would be effectively
    a. one-half degree
    b. one twenty-third degree
    c. unchanged at the output
    d. twenty-three degrees

15. The principal advantage of a multiple-speed transmission system is
    a. higher torque gain
    b. greater stability
    c. more uniform gain
    d. greater accuracy

16. The purpose of damping in any servomechanism is to
    a. reduce oscillation
    b. provide steady rate errors
    c. increase the error transient time
    d. decrease the width of the null

17. The Aviation Fire Control Technician will find himself primarily concerned with the ___________ type of control system.
    a. discontinuous, automatic, closed-loop
    b. continuous, automatic, closed-loop
    c. continuous, automatic, open-loop
    d. discontinuous, automatic, open-loop

18. The component of the data transmission system which compares the input with the servomechanism's output is the
    a. error detector
    b. servo amplifier
    c. servo followup
    d. servomotor

19. The secondary windings of an E transformer being used as an error detector are wound
    a. parallel
    b. shunt
    c. series-aiding
    d. series-opposing

20. The most widely used a-c servomotor is the
    a. two-phase induction motor
    b. split phase a-c motor
    c. split series motor
    d. shunt motor

21. In order to have a zero output from a control transformer, the rotor winding must be ________________ to the stator's magnetic field.
    a. parallel
    b. perpendicular
    c. displaced by 120 degrees
    d. displaced by 240 degrees

CHAPTER 6

TYPICAL AVIATION FIRE CONTROL SERVO SYSTEMS

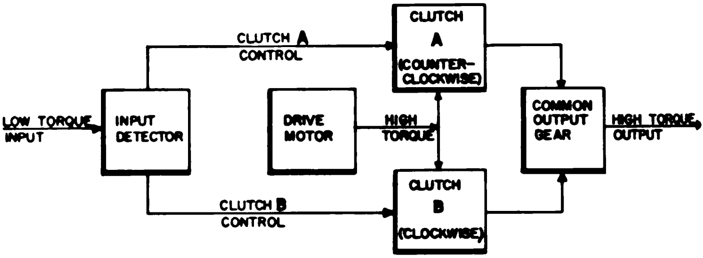
TORQUE AMPLIFIERS

In the last chapter it was shown that the output load of the servomotor, in part, determined the type of servomotor to be used and the amount of amplification required by the servo amplifier. However, in actual practice it is not always possible or desirable to use a motor capable of developing sufficient torque to drive a large load. For example, the output of a servo system may be fed to a computer utilizing a mechanical multiplier which, in turn, positions a load shaft. It would be a simple matter to increase the power handling capabilities of the servomotor, but this would require the multiplier to also be capable of handling the additional torque. To overcome this condition, a torque amplifier may be used.

A torque amplifier is a device for increasing the power output without appreciably altering the quality of the input. To perform satisfactorily, it must contain the necessary essentials of a servomechanism. However, it can be better compared to a closed-loop regulating system. Torque amplifiers used in aviation fire control equipments may be either mechanical or electrical. Each type will be discussed in detail in this chapter.

Mechanical Torque Amplifier

Referring to the block diagram of the torque amplifier (fig. 6–1), it should be noted that output torque or power is derived solely from the constant speed drive motor. The



NOTE: EITHER A OR B CLUTCH MAY BE ENGAGED. NEVER BOTH.

Figure 6–1.—Block diagram of a mechanical torque amplifier.

drive motor transmits its power to the two friction clutches, each rotating in opposite directions. The input detector determines which clutch must be engaged and the degree of coupling required to give an output equal to that of the input. To insure that the input and output are equal, output information is transmitted back to the input. Any difference between the input and output velocity will result in sufficient change in the degree of clutch coupling necessary to cancel this difference.

THEORY OF OPERATION.—A detailed drawing of a typical mechanical torque amplifier is shown in figure 6–2. Particular attention should be given to the cam and cam-follower, noting the resulting action of the balanced T lever with either a clockwise or counterclockwise rotation of the input shaft. In the balanced static condition shown, the cam-follower is located halfway up the inclined plane section of the cam. When an input signal causes the cam to rotate in a clockwise direction, the cam-follower will be lowered, forcing the control lever upward. This motion is coupled to the balanced T lever arm, bringing clutch B into contact with its rotating plate. The clutch transmits power through the gear train, causing the output shaft to also rotate in a clockwise direction. The output shaft is also mechanically linked to the cam-follower gear, causing the cam-follower to rotate at the same velocity as the output shaft. If the output velocity exceeds the input

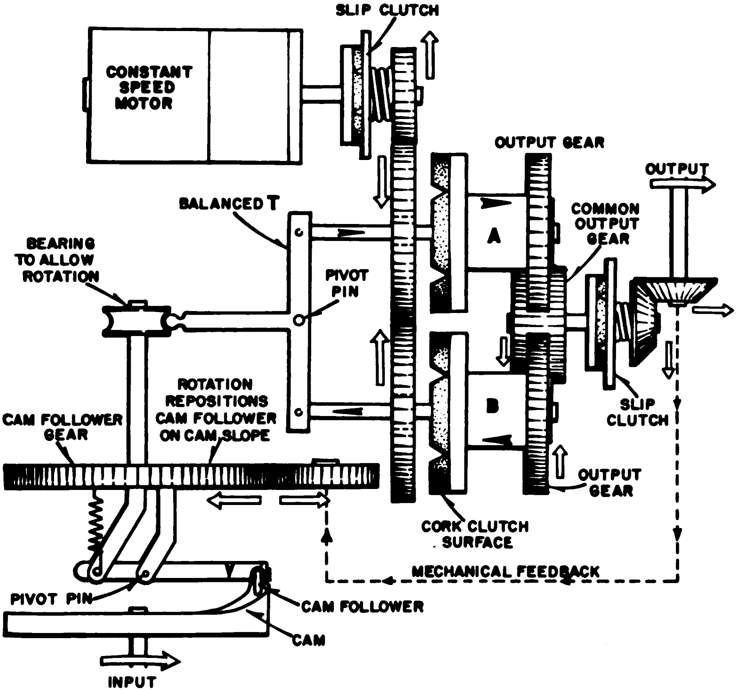


Figure 6–2.—Typical mechanical torque amplifier.

velocity resulting from either overcoupling or a change of input, the cam-follower will change its position on the inclined plane, causing a change in the degree of coupling. A reversal of input will result in clutch A being engaged and the output reversing its direction. The sensitivity of the clutches to respond to any cam-follower displacement determines the amount of velocity lag and dead zone of the amplifier.

Maintenance.—The mechanical torque amplifier, when employed in aviation fire control equipment, is constructed as a small compact unit having very close tolerances. In order for it to function properly, it must be kept clean and properly lubricated. Procedure for cleaning and lubricating the torque amplifier will be found in the *Handbook of*

Service Instructions for the equipment in which it is used. This procedure will include information as to the cleaning solvent and lubricants to be used, and how often and under what conditions cleaning and lubrication should be performed. It will also include disassembling and assembling instructions.

A general procedure for cleaning and lubricating any mechanical mechanism is discussed in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388. However, a few basic considerations will be briefly reviewed. In disassembling or assembling any precision mechanism, extreme care must be exercised not to damage components by misalinement or any other action causing excessive pressure to be applied to precision parts. Gear teeth and other points of wear (except bearings) should be cleaned with the prescribed solvent, exercising care not to allow the solvent to contact bearing surfaces. Remove old and excessive lubricants with a lint-free cloth. The clutches can be cleaned by inserting between the clutch surfaces a clean sheet of white paper dampened with a solvent. Gently close the clutch and rotate one surface at a time, insuring that the paper wipes both surfaces of each clutch. Continue this action until there is no noticeable blackening of the white paper when removed.

A small brush should be used to apply a light coat of grease to all gear teeth and the surfaces of cams that are subject to wear. A few drops of oil should be applied to the surfaces of the friction clutches; the type and amount should follow exactly that directed by the *Handbook of Service Instructions.* Bearings used in torque amplifiers may vary widely with different equipments and should also be cleaned and lubricated as directed.

Electrical Torque Amplifier

An electrical torque amplifier must fulfill the same basic requirements set forth for the mechanical torque amplifier. It contains a means of actuating an electric motor which provides the necessary torque to drive the output shaft and load. A typical electrical torque amplifier is shown in figure 6–3. Unlike the mechanical torque amplifier, the one shown in figure 6–3 is capable of transmitting a limited amount of power from the input shaft to the output shaft with no electrical power applied.

Theory of operation.—Before going into a detailed explanation of the components, consider the functional block

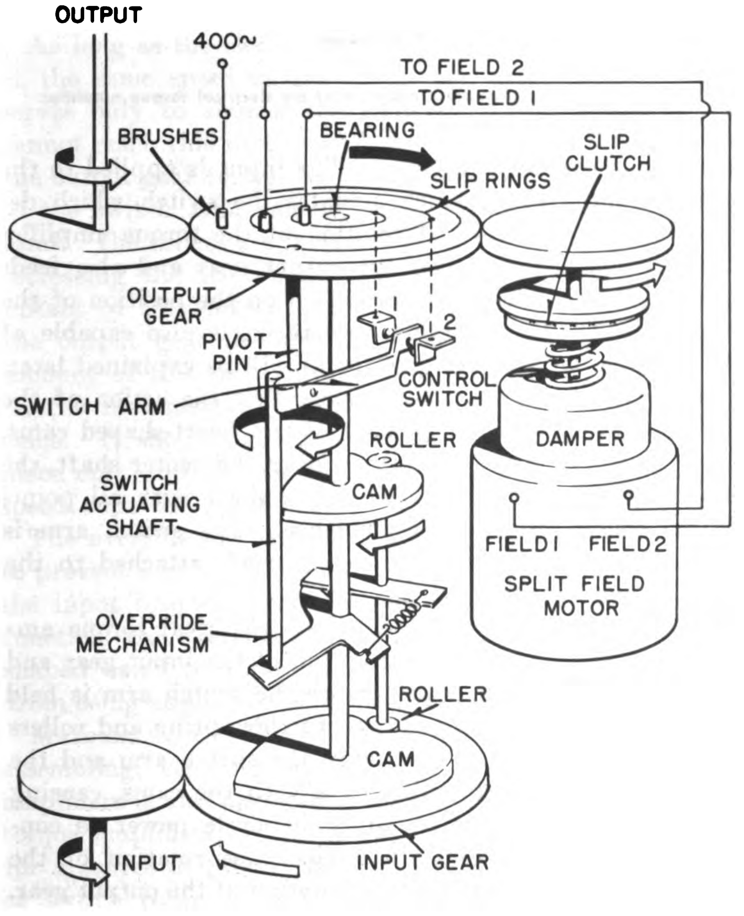


Figure 6–3.—A typical electrical torque amplifier.

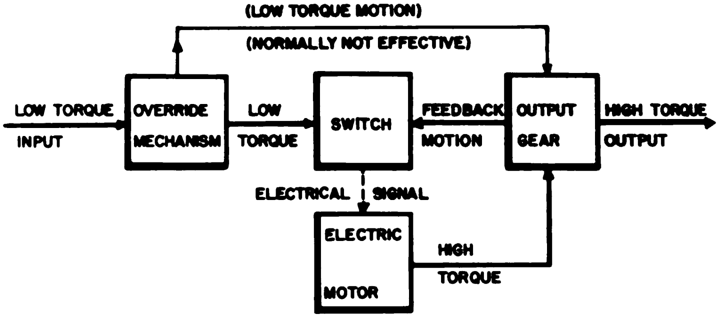


Figure 6–4.—Functional block diagram of an electrical torque amplifier.

diagram shown in figure 6–4. The input is applied to the override mechanism which actuates the switch which determines the direction of rotation of the torque amplifier motor. The motor drives the output gear and also feeds back to the switch unit information on the position of the output load. The override mechanism is also capable of driving the output gear directly as will be explained later.

Referring to figure 6–3, consider first the action of the override mechanism. It consists of two heart-shaped cams, one rigidly attached to the input gear and center shaft, the other rigidly attached to the center shaft with all points of the two cams in correspondence. The switch arm is positioned by the switch actuating shaft attached to the override mechanism.

To illustrate the operation of the electrical torque amplifier, consider a clockwise rotation of the input gear and the two heart-shaped cams. Since the switch arm is held in position by the action of the override spring and rollers resting in the valley of the cams, the switch arm and the switch actuating shaft will rotate with the cams, causing the control switch arm to apply 400-cycle power to contact 2. This will result in a clockwise rotation of the electric motor, counterclockwise rotation of the output gear, and clockwise rotation of the load. The fixed contacts are mounted on the underside of the output gear. When the output gear and input gear are in correspondence, the switch center arm will cease to apply power to contact 2. Since the motor must be capable of driving the output shaft at a speed equal to the highest input speed, normal inputs will cause the switching mechanism to alternately open and close the switch, applying power whenever the output lags the input.

If the input shaft were rotated counterclockwise, the operation of the amplifier would be reversed with the control switch arm applying power to contact 1.

As long as the electric motor can drive the output shaft at the same speed as the input, the override mechanism serves only to actuate the switch. However, the motor cannot reach this input speed instantaneously, thus causing the output gear to lag the input gear. This lag is reflected to the switch arm, causing it to lag the position of the cams. The rollers are forced to move outward on the cams, increasing the tension on the override spring. The resultant of this outward force is transmitted as torque to the output gear through the switching mechanism. The amount of this mechanically coupled torque is dependent on the movement of the switch arm with respect to the cams. It should be kept in mind that this action takes place only until the electric motor can equalize the output speed with the input speed.

The override mechanism is a safety factor incorporated to prevent undue strain on the system components. Should the input torque exceed the output torque due to a malfunction, the override mechanism would allow the heart-shaped cams to rotate, thus preventing excessive strain from being applied to the other components of the amplifier.

MAINTENANCE.—The general procedure for disassembling, assembling, cleaning, and lubricating mechanical torque amplifiers is also applicable, for the most part, to electrical torque amplifiers. However, the use of an electric motor for a source of power requires maintenance of such items as switch contacts, sliprings, and brushes. The general procedure for maintenance of electrical components is discussed in chapter 10 of *Aviation Fire Control Technician 3*, NavPers 10388. However, the *Handbook of Service Instructions* for the specific equipment should always be consulted for detailed information.

COMPUTER SERVO SYSTEM

Computer servo systems used to solve aviation fire control problems are similar to those discussed in the previous chapter. However, they differ in that several inputs are normally applied that will affect the output of the system. The complexity of the fire control problem requires that the solution of one formula be transmitted to other sections of the computer for simultaneous solutions to other formulas.

A typical problem to be solved within a computer utilizing a servo system is represented by the equation

$$J = \frac{R\, t_f}{R_f}.$$

The factor J is a mathematical quantity determined by the factors R (present range of target aircraft), t_f (time of flight of the projectile), and R_f (future range of the target aircraft). The quantity J has no significant meaning other than that it represents the term $\frac{R\, t_f}{R_f}$ in the above equation.

Theory of Operation

As you will recall, the operation of a servomechanism is dependent upon its ability to compare two quantities and feed an error signal to its output member which, in turn, will cause the error signal to be canceled. The servo system can be utilized to give a continuous solution to the problem if the formula is rearranged to give a ZERO OUTPUT. By multiplying both sides of the above equation by $\frac{R_f}{J\, t_f}$ and transposing, the equation can be written as follows:

$$\frac{R}{J} - \frac{R_f}{t_f} = 0.$$

ERROR DETECTOR.—Figure 6–5 shows a typical computer servo system functional diagram that is capable of giving a continuous solution to the above problem regardless of its continuously changing inputs. Unlike the error detectors studied in the previous chapter, the computer error detector has three inputs and one output.

Before considering the input voltages to the error detector, let us re-examine the equation to be solved by the servo system. The equation requires that the value of R_f be divided by the value of t_f. The simplest method to divide in a computer is to take the reciprocal of the divisor and multiply it by the dividend. This can be done by the use of potentiometers as shown in figure 6–5. It should be noted that the output of the servo system $\frac{1}{J}\cdot$ is also a reciprocal function. This creates no particular problem since J is only a mathematical quantity that could be changed from its reciprocal form if required.

The inputs to the system consist of two electrical voltages and a shaft position. A negative potential is applied to the top of R_1, the amplitude of which is proportional to the future range of the target aircraft (R_f). The center arm of R_1 is positioned by a mechanical input, the position of which is indicative of $\frac{1}{t_f}$. Thus, the negative voltage

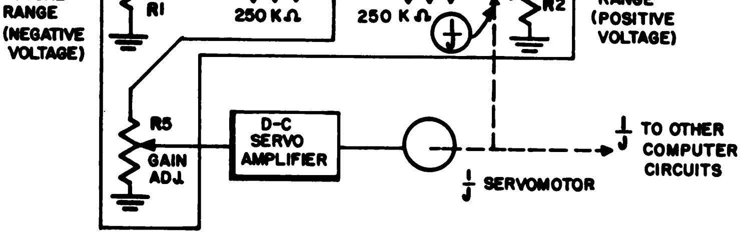

1/tf TO OTHER COMPUTER CIRCUITS
1/tf SERVOMOTOR
Rf
TARGET FUTURE RANGE (NEGATIVE VOLTAGE)
1/tf
Rf/tf
R/J
R3
(NULL) R4
R1
250 KΩ
250 KΩ
R
TARGET RANGE (POSITIVE VOLTAGE)
R2
R5
GAIN ADJ.
D-C SERVO AMPLIFIER
1/J SERVOMOTOR
1/J TO OTHER COMPUTER CIRCUITS

Figure 6–5.—Typical computer servo system functional diagram.

at the center arm of R_1 is a function of $\frac{R_f}{t_f}$. A positive voltage is applied to the top of R_2 which is proportional to the present range of the target aircraft. The negative voltage at the center arm of R_1 and the positive voltage at the center arm of R_2 are summed across R_3 and R_4 with the error voltage being one-half of this sum.

SERVO AMPLIFIER.—The servo system accomplishes the solution to the problem by amplifying the error voltage and applying it to the servomotor in such a manner that it will position the shaft of R_2, giving a zero error voltage output. The amplifier, motor, and data transmission system required to complete the servo system are similar to those discussed in the last chapter. However, a gain control, R_5, is used to control the gain of the servo loop or system.

Because of the friction and inertia, a certain minimum amount of torque is required to rotate the potentiometer shaft. At low signal levels the torque output of the servomotor can be below the minimum value required to drive the potentiometer to its null position. This results in radial play or a dead zone in the shaft motion, which, if too large, can cause excessive errors in computation. The dead zone can be reduced by adjusting the servo gain control to increase the THRESHOLD of the servo with a larger proportion of the input error signal applied. Too large an input, however, causes the servomotor to drive the follow potentiometer beyond the proper nulling point. This overshoot produces an error signal of opposite polarity causing a reversal of the servomotor.

In such a system the servo cannot find the correct nulling point and an oscillatory condition termed JITTER results. Jitter usually occurs when loop gain has been increased to such an extent that the servo seeks its null between two adjacent turns on the follow potentiometer. A small amount of dead zone is desirable to prevent such hunting.

Since some computer servo systems utilize a-c error de-

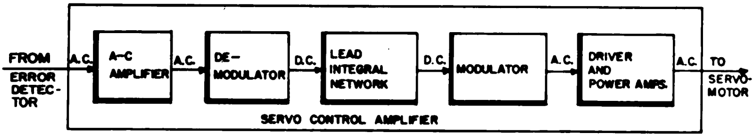


Figure 6–6.—Block diagram of servo control amplifier.

tectors, a-c servo amplifiers will also be discussed. Systems utilizing a-c error signals are subject to an undesirable phase shift due to the reactance of the servo system. A block diagram of a typical computer servo a-c amplifier is shown in figure 6–6. The function of each block should be considered before going into the circuitry, which is as follows:

A-C AMPLIFIER—to amplify the a-c error signal sufficiently to drive the circuits that follow.

DEMODULATOR—to change the a-c error signal to a d-c voltage. It also rejects any signal that is not either in phase or 180 degrees out of phase with the reference voltage.

LEAD INTEGRATOR NETWORK—provides correction for phase lag of the amplifier.

MODULATOR—converts the d-c error signal to an a-c error signal.

DRIVER AND POWER AMPLIFIER—amplifies the error signal sufficiently to drive the servomotor.

SERVOMOTOR—drives the load to cancel the error signal.

The schematic diagram of a typical servo a-c amplifier used in computers is shown in figure 6–7. Much of the theory of operation is covered in *Basic Electronics*, NavPers 10087, and chapter 5 of this course. However, the variations from the basic circuits will be discussed in this chapter.

The A-C AMPLIFIER is a conventional CLASS A AMPLIFIER, utilizing a gain control potentiometer. The gain of the stage is determined by the setting of R_1 which also controls the gain of the entire servo system. This stage also contains a balance control (R_6) not normally found in amplifiers of this type. Before considering the operation of the balance control, we should consider why it was in-

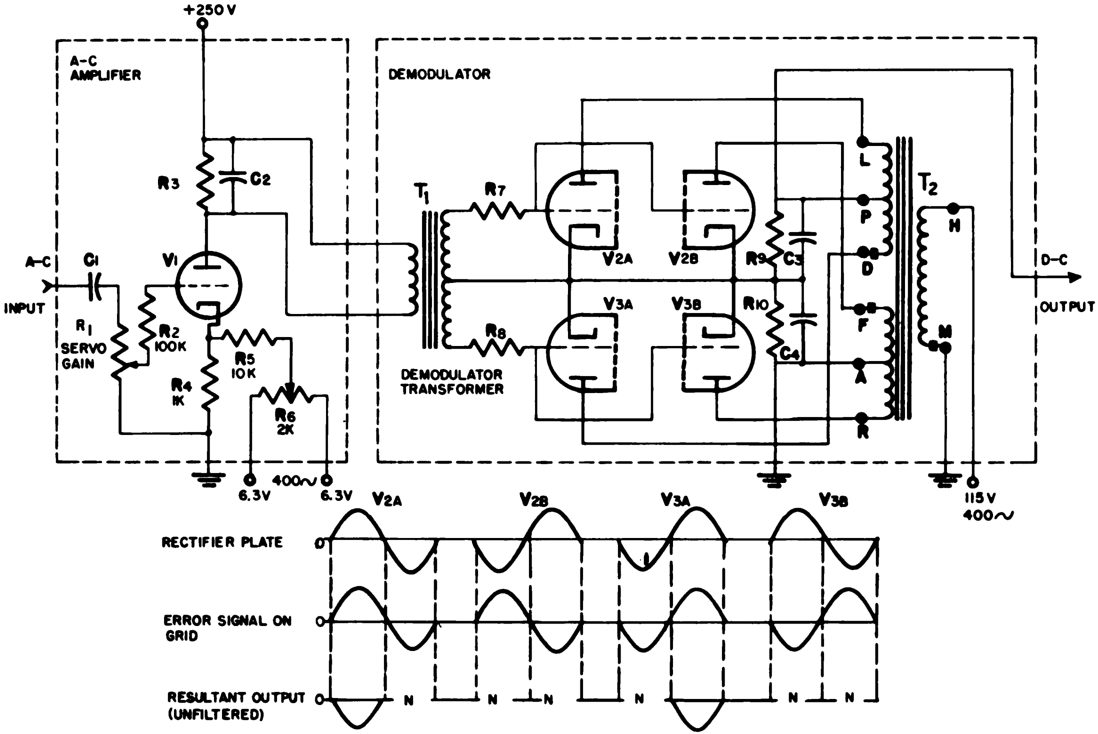


Figure 6–7.—A-c amplifier and demodulator, schematic diagram.

cluded. Ordinarily, there is a certain amount of static unbalance in the various stages of the servo amplifier. This unbalance could cause the servomotor to rotate with no error signal applied. Such action could cause hunting or false readings in the system. The purpose of the balance control is to insure that this condition does not exist.

The balance control R_6 is connected to a 6.3-volt, 400-cycle power having the same phase relationship as the reference voltage. The phase and amplitude of the voltage applied to the cathode of V_1 is determined by the position of the center arm of R_6. With R_1 adjusted for zero signal input, R_6 is adjusted to apply a signal to the cathode of V_1, the results of which will cancel the effects of any unbalance in the amplifier.

The DEMODULATOR, sometimes called detector, insures rejection of quadrature or unwanted signals by comparing the phase of the error voltage with the reference voltage. The error signal, after being amplified by V_1, is applied to T_1 and the secondary voltages are applied to the grids of both sections of V_2 and V_3. Voltages from the two secondary windings of the reference transformer T_2 are applied to the plates of V_2 and V_3, and these voltages are either in phase or 180 degrees out of phase with the error voltage on the grids.

Consider first the 180-degree out-of-phase relationship of error signal to reference voltage shown at the bottom of figure 6–7. On the positive half cycle of reference voltage, V_{2A} conducts because the signal voltage on the grid is also positive. However, none of the other tube sections can conduct because positive half cycles do not appear simultaneously on their plates and grids. On the negative half cycle of reference voltage the process is repeated, with only V_{3A} conducting. Therefore, when the error signal and reference voltage are 180 degrees out of phase, current flows on alternate half cycles through the circuit consisting of the following:

FIRST HALF CYCLE—current flows from the cathode to the plate of V_{2A} to pin L of T_2, through the secondary of

T_2 to pin P, then through R_9 back to the cathode of V_{2A}.

SECOND HALF CYCLE—current flows from the cathode to the plate of V_{3A} to pin D of T_2, through T_2 to pin P and through R_9 and back to the cathode of V_{3A}.

The train of negative pulses resulting from this demodulator action is smoothed and filtered by R_9 and C_3 and the output is a substantially smooth, negative d-c potential. When the error signal and the reference voltage are in phase, conduction will be through V_{3B} and V_{2B} on alternate half cycles, and R_{10}. The output voltage will be positive and filtered by the action of C_4 and R_{10}.

The d-c output of the demodulator is applied to a half-wave modulator as shown in figure 6–8 through a LEAD-INTEGRAL NETWORK designed to speed the response of the servomotor in order to prevent hunting and jitter. The network, consisting of R_1, R_2, C_1, and C_2 corrects the phase shift through the various stages of the servo amplifier, which, at the initial application of error voltage, would otherwise cause the servomotor to be faulty in its response.

The MODULATOR in figure 6–8 consists of R_4, R_5, V_{1A} and V_{1B}, and a reference voltage transformer which supplies a 400-cycle reference. The purpose of the modulator is to convert the d-c output of the demodulator into a voltage

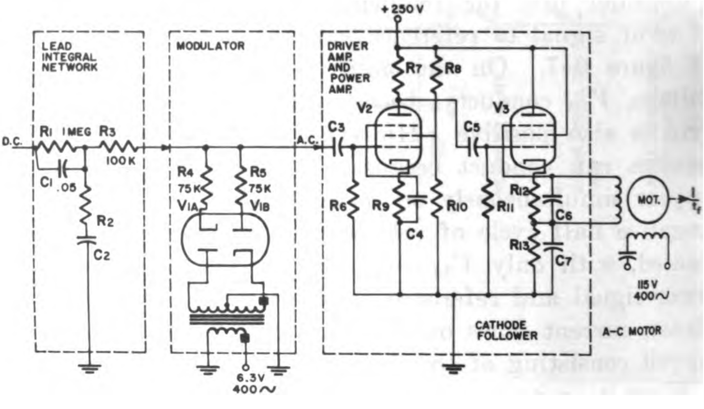


Figure 6–8.—Modulator, driver amplifier, and power amplifier.

suitable for a-c amplification to drive the motor. This is accomplished by effectively shortcircuiting the voltage at the junction of R_4 and R_5 to ground every other half cycle. When the voltage on the plate of V_{1A} is negative, the voltage on the cathode of V_{1B} is positive and neither tube can conduct. On the other half cycle the polarities reverse and both V_{1A} and V_{1B} conduct through R_4 and R_5. Since the secondary of the reference transformer has a grounded center tap, an apparent ground is produced at the junction of the two resistors, and the d-c signal at this point drops to zero. Since the uncontrolled winding of the servomotor is excited by a voltage 90 degrees out of phase with the reference voltage, the output of the modulator is of the proper phase (leading or lagging the uncontrolled winding voltage by 90 degrees) for motor rotation.

The output of the modulator is amplified by the driver amplifier V_2 and fed to V_3, a power amplifier. The output of the power amplifier energizes the controlled winding of the servomotor with the direction of rotation being determined by the polarity of the d.c. from the demodulator. The motor torque is proportional to the magnitude of the error signal.

ANTENNA SERVO SYSTEM

In this section we will discuss the application of a servomechanism to position a radar antenna and supply target information to the fire control system. However, before discussing the servo system, we will consider the scan pattern of a typical aviation fire control system.

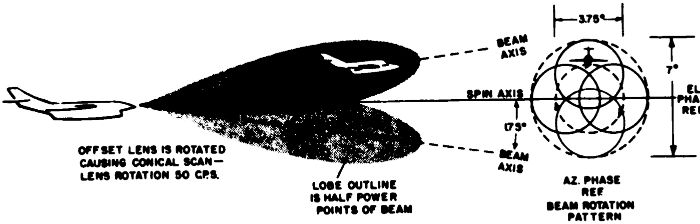

3.75°
BEAM AXIS
7°
SPIN AXIS
EL. PHASE REF
1.75°
BEAM AXIS
OFFSET LENS IS ROTATED CAUSING CONICAL SCAN— LENS ROTATION 50 CPS.
LOBE OUTLINE IS HALF POWER POINTS OF BEAM
AZ. PHASE REF
BEAM ROTATION PATTERN

Figure 6–9.—Antenna beam with conical scan.

The antenna radiator and reflector form a conical pattern of circular symmetry with beam dimensions as shown in figure 6–9. The antenna assembly contains a spinner motor that rotates the beam about the antenna axis to produce a 7-degree conical scan. While the radar is in the search mode of operation, the rotating cone is scanned both horizontally and vertically, covering an area of 10 degrees vertically by 90 degrees horizontally. (See fig. 6–10.) The search pattern may be positioned vertically from a positive 30 degrees to a negative 30 degrees by the antenna positioning lever.

The operator will normally observe the targets, identify each as friend or foe, and determine which target, if any, to pursue. Since the antenna utilizes its 7-degree conical pattern only during track operation, some means must be provided for positioning the antenna on the selected target to begin the track operation. This is accomplished by bracketing the selected target with strobe lines. When the target has been selected and bracketed, a LOCK-ON switch is depressed, positioning the antenna on the predetermined target and placing the equipment in the automatic track

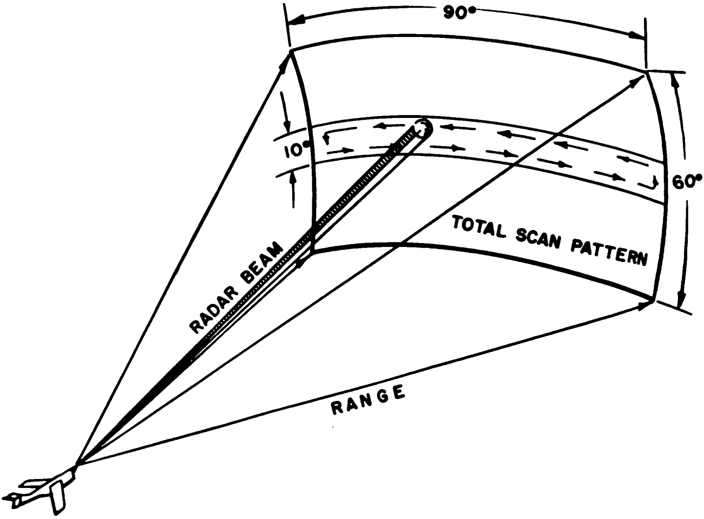


Figure 6–10.—Typical antenna scan pattern.

mode of operation. The antenna is now positioned by the radar receiver output, keeping the target centered in the 7-degree beam.

Components

A block diagram of a typical fire control antenna servo system is shown in figure 6–11. It should be noted that the azimuth channel of the antenna control system has been omitted as its operation is similar to the elevation channel. Since the antenna servo system utilizes different components during search and track operation, the system used in each mode of operation will be discussed separately.

SEARCH OPERATION.—The main components of the antenna servo system used during search operation are:

1. Error detector and its a-c voltage source.
2. Servo amplifier.
3. Servomotor.
4. Data transmission system.

The a-c generator supplies voltage to the input and feedback potentiometers of the balanced potentiometer error detector. However, the voltage fed to the input potentiometer is fed through a gyro space stabilizer and scan generator.

The function of the gyro space stabilizer is to cause the antenna to scan a selected area 90 degrees horizontally and 10 degrees vertically, regardless of any roll or pitch of the aircraft. As in all fire control equipment of this type, the amount of correction that can be made by the gyro space stabilizer is limited by the limit of the radar scanner. The output of the gyro space stabilizer is an a-c voltage, the amplitude of which is a function of the roll and pitch of the aircraft. The principles of operation of gyros will be discussed later in this course.

The function of the vertical scan generator is to automatically position the antenna in the vertical plane. Referring to figure 6–10, you will note the antenna scans horizontally and vertically. The scan generator provides the necessary voltage change to cause the antenna to change

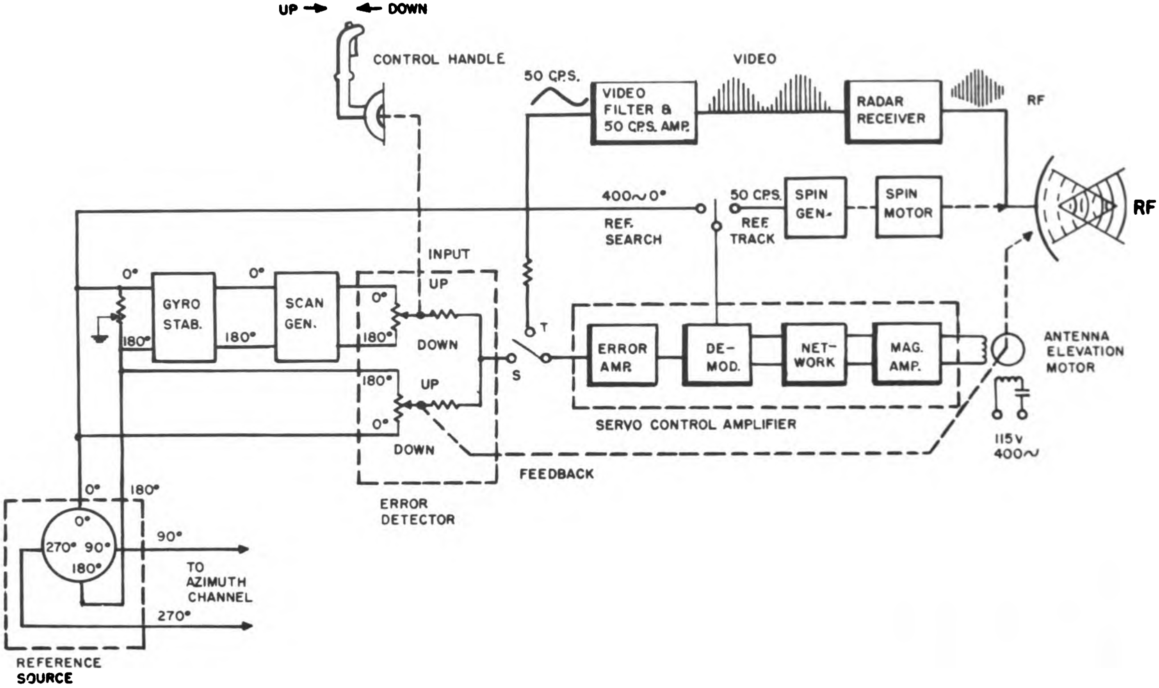


Figure 6–11.—Functional block diagram of antenna elevation servo systems.

its angle of elevation by 3 degrees when the antenna reaches its azimuth limits.

The error detector has 3 inputs that are summed and compared against the antenna's position. The gyro space stabilizer and scan generator constitute 2 inputs by controlling the amplitude of the voltage supplied the input potentiometer. The third input is the control handle which positions the wiper contact of the input potentiometer. The output of the error detector is an a-c voltage whose amplitude and phase is determined by the voltage on the wipers of the potentiometers.

The error signal is fed to the servo amplifier where it is amplified and compared with the phase of the reference voltage. The phase of the output voltage causes the servomotor to rotate in a direction reducing the error voltage.

The data transmission system is the mechanical linkage necessary to drive the wiper of the feedback potentiometer, indicating the actual position of the antenna in the vertical plane at all times.

TRACK OPERATION.—The main components of the servo system employed during track operation are:

1. Radar receiver and 50-cycle amplifier.
2. Servo amplifier.
3. Servomotor.
4. 50-cycle spin generator.

The radar receiver functions as the error detector, supplying a 50-cycle error voltage. Before discussing the other components of the system, we shall first determine how the receiver provides the error signal. As stated previously, the antenna axis is centered approximately on a target prior to going into track operation. The antenna is rotating at 50 revolutions per second while the radar transmitter is transmitting a pulse of energy 450 times per second. When the antenna axis is pointing directly at the target, the target return and receiver video output remain at a constant level. However, if the target was above the antenna axis as shown in figure 6–12, the amplitude of the video would vary as the antenna rotated about its axis. It

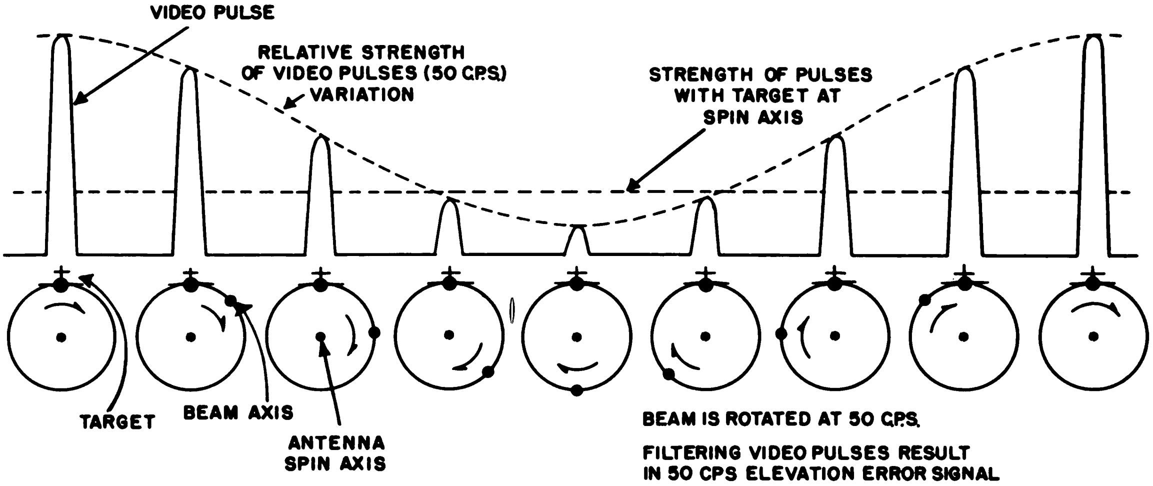

VIDEO PULSE
RELATIVE STRENGTH OF VIDEO PULSES (50 C.P.S.) VARIATION
STRENGTH OF PULSES WITH TARGET AT SPIN AXIS
TARGET
BEAM AXIS
ANTENNA SPIN AXIS
BEAM IS ROTATED AT 50 C.P.S.
FILTERING VIDEO PULSES RESULT IN 50 CPS ELEVATION ERROR SIGNAL

Figure 6–12.—Derivation of elevation error signal.

should be noted that the video amplitude is maximum when the beam axis is at its highest elevation and minimum when the beam axis is at its minimum elevation. The video output from the receiver is filtered, leaving only the 50-cycle envelope to be employed as an error voltage.

The function of the servo amplifier is to amplify the 50-cycle error voltage and compare its phase with the phase of the 50-cycle reference voltage originating in the 50-cycle spin generator. The phase of the output voltage to the servomotor causes the motor to rotate in the direction reducing the amplitude of the error signal.

Theory of Search Operation

The schematic diagram of the antenna servo system described above is shown in figure 6–13 (A) and (B). As in the case of the block diagram, the system's search mode of operation will be discussed first.

SCAN GENERATOR.—The elevation scan generator is utilized during automatic search only. It consists of two resistors and one double-pole relay. Since only one resistor is in the circuit at a time, they serve to unbalance the voltage applied to the error-detector potentiometer R_3. The input to the scan generator is an a-c voltage with its center point grounded by a resistor network. With both R_1 and R_2 shorted, the center of R_3 would also be ground potential. Inserting R_1 in the circuit would cause the center of R_3 to be at some potential just as though the wiper of R_3 had been moved to the right. Shortening R_1 and inserting R_2 would EFFECTIVELY move the wiper of R_3 to the left.

The relay is actuated by a cam attached to the azimuth limit mechanism that operates when the antenna reaches either azimuth limit.

ERROR DETECTOR.—The balanced potentiometer error detector consists of potentiometers R_3 and R_{35}. Potentiometer R_{35} is supplied with a 400 c.p.s. reference voltage of approximately 32 volts amplitude while the reference voltage applied to R_3 is modified as discussed above. This voltage source is center tapped and grounded which reflects an

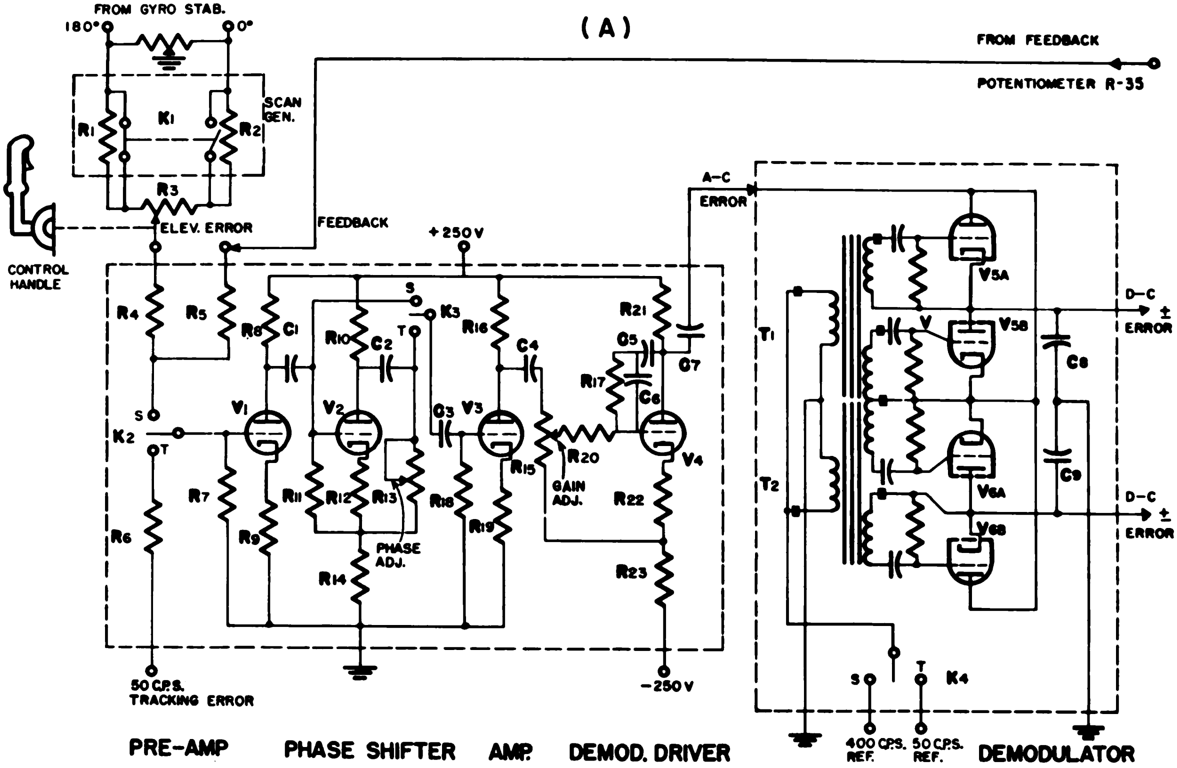


Figure 6—13.—(A) Servo system schematic diagram.

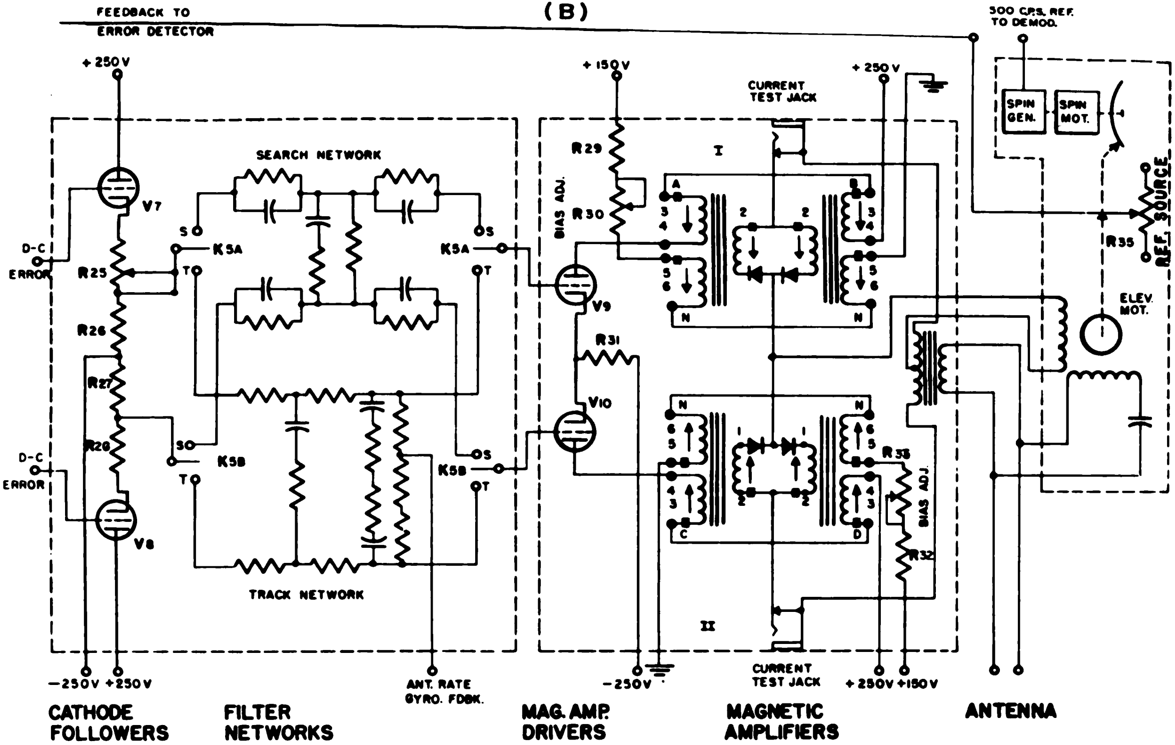


Figure 6—13.—(B) Servo system schematic diagram.

apparent ground at approximately the center of each potentiometer. A control handle displacement causing a change in the wiper contact of R_3 will result in an unbalanced voltage condition with an error signal being fed to the search contact of relay K_2. With the equipment on search, the error signal is applied to the servo amplifier.

SERVO AMPLIFIER.—The servo amplifier consists of the following stages:

1. Preamplifier.
2. Phase shifter amplifier.
3. Amplifier.
4. Demodulator driver.
5. Demodulator.
6. Cathode followers.
7. Search-track network.
8. Magnetic amplifier drivers.
9. Magnetic amplifier.

PREAMPLIFIER V_1 receives the error voltage from relay K_2 where it is amplified. The preamplifier output is coupled through C_1 to the grid of V_2 and to the relay K_3.

PHASE SHIFTER AMPLIFIER V_2 is bypassed during search operation and will be discussed under track operation.

AMPLIFIER V_3 provides an additional stage of amplification of the error signal. Its output is coupled through C_4 to the gain control R_{15}. The gain control determines the amplitude of the error signal fed to the demodulator driver. Thus, the gain of the antenna servo system is controlled by R_{15}.

The DEMODULATOR DRIVER provides the final amplification of the error signal prior to demodulation. As pointed out above, the amplitude of the signal applied to the grid can be controlled by the gain potentiometer (R_{15}). The gain of the stage is stabilized by degenerative feedback. The feedback is accomplished by two means, an unbypassed cathode resistor R_{22} and a plate-to-grid feedback loop consisting of C_6, C_5, and R_{17}. In addition to gain stabilization, the plate-to-grid loop provides the characteristic of an error-rate damper.

To fulfill these requirements, the stage must provide a means of advancing the phase of the error signal with an increase in its amplitude. This can be accomplished by varying the grid-to-plate capacitance with the amplitude of the error signal. Let us examine the effect a change in input amplitude will have on the feedback loop capacitance. If the amplitude of the error signal is increased by one volt, the change in plate voltage is (A + 1) where A is the gain of V_4. Although there has been no change in capacitance, the effective capacitance has increased by the factor (A + 1) due to the higher charge the capacitor is now capable of acquiring. This EFFECTIVE change in grid-to-plate capacitance is commonly referred to as MILLER EFFECT. The output of the demodulator driver is capacitive coupled by C_7 to the demodulator tubes (V_{5A}, V_{5B}, V_{6A}, V_{6B}).

The full-wave DEMODULATOR employs the use of two dual triodes, V_5 *and* V_6. Its operation is somewhat similar to the triode demodulator discussed in the last chapter. The input error signal from the demodulator driver is applied to either the plate or cathode of the demodulator triodes. The reference voltage, which is 400 cycles per second during search operation, is supplied to the grids through either T_1 or T_2 with the primary-secondary phase relationship as shown in figure 6–13 (A). Figure 6–14 shows a synchrogram of the voltages existing in the demodulator. It should be noted that when the error signal and reference voltage are in phase, V_{5A} conducts on the first half cycle and V_{6A} conducts on the second half cycle. Since V_{5B} is cut off during the time V_{5A} is conducting, V_{5A} draws electrons from the top plate of C_8, charging it positive. During the second half cycle, electrons flowing through V_{6A} are deposited on the lower plate of C_9, charging it negative. This action results in a push-pull output being supplied to the cathode followers.

When the error signal is 180 degrees out of phase with the reference voltage, V_{5B} and V_{6B} will conduct on alternate half cycles, charging C_8 and C_9 to the opposite polarity.

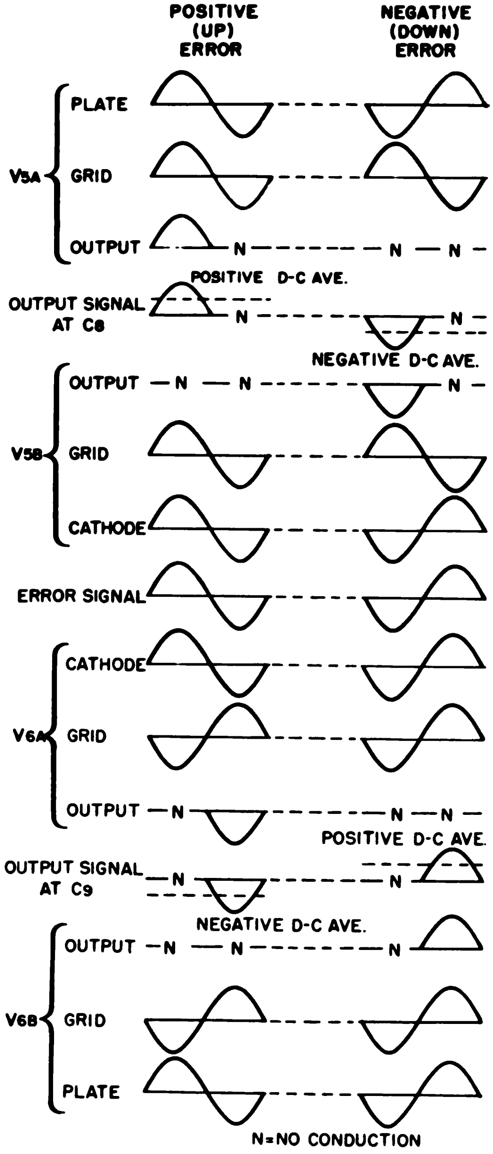


Figure 6–14.—Synchrogram of demodulator waveforms.

The CATHODE FOLLOWERS, V_7 and V_8, isolate the d-c output of the demodulator from the low impedance of the search network. (See fig. 6–13 (B)). Potentiometer R_{25} is provided to balance the outputs of V_7 and V_8 when no error signal is present.

The SEARCH-TRACK NETWORK consists of two R–C band-pass filter networks which have fairly long time constants. The search filter networks pass a 5 c.p.s. signal while sharply attentuating lower frequencies. This action counteracts the high gain of the magnetic amplifiers giving a flater overall response for the servo system.

The MAGNETIC AMPLIFIER DRIVERS are d-c amplifiers that control the current through the magnetic amplifier's control windings. The d-c error signal is applied directly to the control grids of the drivers. The amplified d-c error signal is applied to the control windings controlling the output of the magnetic amplifier.

The MAGNETIC AMPLIFIER provides the final stage of amplification of the error signal prior to the servomotor or output member. The amplifier consists of four amplifier sections, A, B, C, and D. Each amplifier section has three windings on its core—control, bias, and load. Referring to figure 6–13 (B), note that the control and bias windings of sections A and B are connected in series. The bias level is determined by the setting of potentiometer R_{30}, and the control current is determined by the output of magnetic amplifier driver V_9. The C and D sections are connected in a similar manner with the bias level determined by potentiometer R_{33} and control winding current determined by the output of magnetic amplifier driver V_{10}. It should also be noted that the load winding of each section has a dry disk rectifier connected in series with it, allowing current to flow only in one direction. The polarity of the magnetic field resulting from current in each winding is indicated on the schematic by the direction of the arrows.

A synchrogram of waveforms illustrating the operation of the magnetic amplifier is shown in figure 6–15. With a

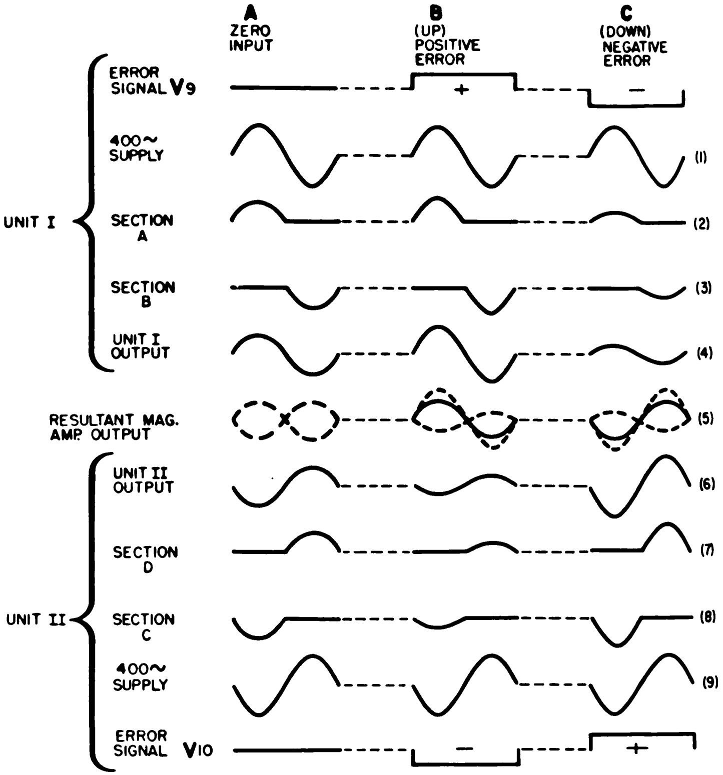


Figure 6–15.—Magnetic amplifier synchrogram.

zero error signal applied to the grids of V_9 and V_{10}, conduction in all sections of the amplifier is equal. Waveforms showing the amount and time of conduction of each amplifier section under zero error signal conditions are shown in column *a* of figure 6–15. It should be noted that waveforms 4 and 6 are equal in amplitude but 180 degrees out of phase resulting in the zero output to the servomotor.

Column *b* of figure 6–15 illustrates the operation of the amplifiers with a positive error (an error signal that would cause the antenna elevation angle to be increased) applied to the magnetic amplifier drivers. The positive voltage applied to the grid of V_9 increases the degree of core saturation, reducing the impedance of amplifier sections A and B. The negative voltage applied to the grid of V_{10} decreases the degree of core saturation, increasing the impedance of amplifier sections C and D. Since the output of a magnetic amplifier varies indirectly with its impedance, the output of sections A and B is increased in amplitude while the output of sections C and D is reduced in amplitude. Waveform 5 shows the algebraic sum of the two waveforms which is fed to the servomotor.

Column *c* of figure 6–15 illustrates the operation of the amplifiers with a negative error signal applied. It should be noted that the output amplitudes have been reversed, causing the signal applied to the servomotor to be 180 degrees out of phase with that in column *b*.

SERVOMOTOR.—The servomotor is a split phase a-c induction motor whose field windings are excited by voltages that are 90 electrical degrees out of phase. The output of the servo amplifier determines whether the control winding is leading or lagging the uncontrolled winding. This phase relationship also determines the direction of rotation of the servomotor.

Theory of Track Operation

The purpose of the antenna servo system during track operation is to position the antenna based on the video output of the radar system. Again referring to figure 6–13 (A) and (B), note that relay K_2 disconnects the error detector and control handle from the servo loop. The 50 c.p.s. envelope of the video output constitutes the error signal and is fed to the servo amplifier.

SERVO AMPLIFIER.—The 50 c.p.s. error signal is amplified by the preamplifier and fed to the phase shifter. The phase shifter amplifies the error signal and also provides an adjustment, R_{13}, to compensate for any phase shift of the error signal through the servo amplifier. The output of the plate is coupled through C_2 to R_{13} with the other end of R_{13} connected to the junction of R_{11} and R_{12}. The plate and cathode voltages are 180 degrees out of phase and regenerative current flows in R_{12}, resulting in regenerative feedback. The shifting of the phase of the error signal is accomplished by varying the resistive-reactive ratio of the plate-to-cathode feedback loop. This varies the phase of the regenerative feedback, controlling the phase of the output error signal.

The operation of the amplifier and demodulator driver stages is identical under both modes of operation. However, the demodulator must now employ a 50 c.p.s. reference voltage. Relay K_4 is energized by the track-search switch, disconnecting the 400 c.p.s. reference and connecting the 50 c.p.s. reference supplied by the 50 c.p.s. spin generator.

The outputs of the demodulator are fed through the cathode followers to the track section of the search-track networks. The track section is composed of two identical R–C band-pass filters, which pass 2 c.p.s. signals and attenuate all other signals. A signal from the elevation rate gyro is also used to control the error signal amplitude during track operation.

Since the magnetic amplifier drivers and magnetic amplifier utilize d-c error signals only, their operation is unchanged when switched to track operation.

50 C.P.S. SPIN GENERATOR.—The 50 c.p.s. spin generator is a permanent magnet a-c generator that is driven by the spin motor. Its only function is to furnish a reference voltage for the demodulator during track operation.

Maintenance

The maintenance of the antenna servo system is normally covered during the intermediate and major inspections of the entire fire control system. However, it is the purpose of this section of the chapter to discuss maintenance pertinent to a typical antenna servo system.

LUBRICATION.—The lubrication of the antenna system should follow the procedure set forth in the *Handbook of Service Instructions* for the equipment. The lubricants and the time interval between lubrications should also be in accordance with standards established by the service instructions. Instructions will normally be issued by the squadron supplying supplemental maintenance information and establishing schedules to be followed by maintenance personnel.

ALINEMENT.—The procedure for alinement of the antenna servo system will also be found in the *Handbook of Service Instructions* for each equipment. However, the alinement procedures applicable to the basic antenna servo system will be discussed in this chapter.

The first adjustment to be made will be the BALANCE control, R_{25}. Its purpose is to insure that there is no output from the servo amplifier when no error signal is applied. Connect a d-c voltmeter between the grid of V_9 and the grid of V_{10}. Place a jumper between the grid of V_7 and the grid of V_8. We have now shorted out any error signal and can determine any unbalance of the cathode followers. Adjust R_{25} until there is a zero voltage reading on the voltmeter. Remove the voltmeter from the circuit but do not disconnect the jumper as it will be required for the next adjustment.

The BIAS adjustments in the magnetic amplifiers are made by connecting a milliamp meter in the load winding of each amplifier and adjusting the bias controls, R_{30} and R_{33}, to the current specified by the *Handbook of Service Instructions.* A current jack is normally incorporated in the equipment to facilitate the use of standard milliamp meters. Remove the jumper from the grids of the cathode followers and disconnect the meter.

The gain adjustment is made by inserting a voltage of a specific amplitude and frequency at the input of the preamplifier and measuring the output of the demodulator driver V_4, which is the last a-c amplifier stage. The *Handbook of Service Instructions* will normally specify the amplitude and frequency of the input signal as well as that of the output stage.

The phase adjustment is made when the equipment is in track operation and locked on a strong target. Disable the antenna azimuth channel by removing the demodulator tubes or at some other location specified by the *Handbook* *of Service Instructions.* With the equipment operating as specified above, manually rotate the antenna in azimuth. Any change in the elevation of the antenna indicates an undesirable phase shift in the amplifier. The phase adjustment must be varied until any movement of the antenna in azimuth causes no change in its elevation.

Adjustment potentiometers normally have locknuts to prevent vibration from affecting their setting. The locknut must be loosened prior to adjusting and care taken when tightening in order not to disturb its setting. The locknut is normally sealed with glyptol to prevent the locknut being loosened due to vibration.

ELECTROHYDRAULIC SYSTEM

Introduction

In the servo systems previously discussed, the power required of the output member has been relatively small. However, aircraft turrets are normally large, requiring the output member of the controlling servomechanism to be capable of developing several horsepower. The output member must also be capable of meeting a large peak power demand and having a minimum response time if the turret is to be effective against modern aircraft.

These requirements can best be satisfied by an electrohydraulic system. A hydraulic system offers the following advantages:

1. The hydraulic motor can develop greater horsepower per pound of weight than any other type of motor.

2. The system can meet large peak power demands for reasonable time durations. This can be done by either storing hydraulic fluid under pressure in an accumulator or by maintaining a variable displacement pump at a constant speed.

3. The time of response to a given order is minimum since a constant pressure is maintained by the pump.

A disadvantage of a complete hydraulic system is that it is not easily adapted to remote operation. However, with the use of electromagnetic valves, operation of the system can be remotely controlled by the output of small electrical components. This offers an additional advantage in that the hydraulic system can be made extremely compact further reducing its weight.

A turret must position its guns in both the horizontal and vertical planes in order to position its firepower. Since similar systems are used for both planes, this discussion will be limited to the vertical plane.

A functional block diagram of a typical electrohydraulic system used to control the vertical movement of a turret is shown in figure 6–16. The system may be divided into two sections—electrical and hydraulic. The electrical section is used to transmit the desired positioning information from the gunner's remote position to the turret. The hydraulic system furnishes the power to position the turret based on information received from the electrical section.

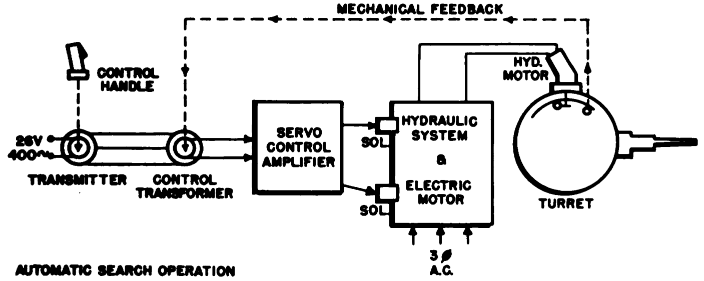


Figure 6–16.—Functional block diagram of an electrohydraulic controlled turret.

The above system may be compared with the basic servomechanism discussed in the previous chapter. The electrical section determines the error signal, amplifies it, and feeds it to the output member. The output member, the hydraulic section, supplies the necessary power amplification and positions the turret through the necessary mechanical linkage. The position of the turret is fed back to the electrical system for comparison with the input signal, thus constituting the data transmission system and completing all the requirements of a servomechanism.

Theory of Operation

Overall system.—An input motion of the control handle in the vertical plane displaces a synchro transmitted whose output is transmitted to a control transformer located at the turret. The error voltage, based on the difference between the desired position and actual position of the turret, is fed to the turret servo control amplifier where it is amplified, demodulated, modified by a network, and again amplified. The output, a d-c error voltage, is used to control the operation of the hydraulic system.

The hydraulic system consists of a variable displacement pump driven by a constant speed three-phase electric motor, a solenoid actuated valve used to control the displacement of the pump, a hydraulic motor, and connecting lines. The d-c error voltage is applied to the solenoid actuated valve which, in turn, controls both the direction and quantity of flow of hydraulic fluid to the hydraulic motor. The hydraulic motor positions the turret, thus causing cancellation of the error voltage.

The tracking of high speed modern aircraft must be accompanied automatically to insure a high degree of accuracy. A radar is employed to supply information on range and the position of the target aircraft relative to the gun platform. The turret must utilize this information, making the necessary lead corrections and directing its firepower at a future target position to be effective.

A functional block diagram of a turret servo system, when in automatic track mode of operation, is shown in figure 6–17. It should be noted that the means of transmitting the position information is modified from the system shown in the previous diagram to increase the accuracy of the system.

The radar scanner supplies the target position information for transmission to the turret. During automatic track operation, the accuracy demanded for the transmission system exceeds the ability of a single-speed synchro system. Thus, a 2-speed synchro system is employed to position the turret during this mode of operation.

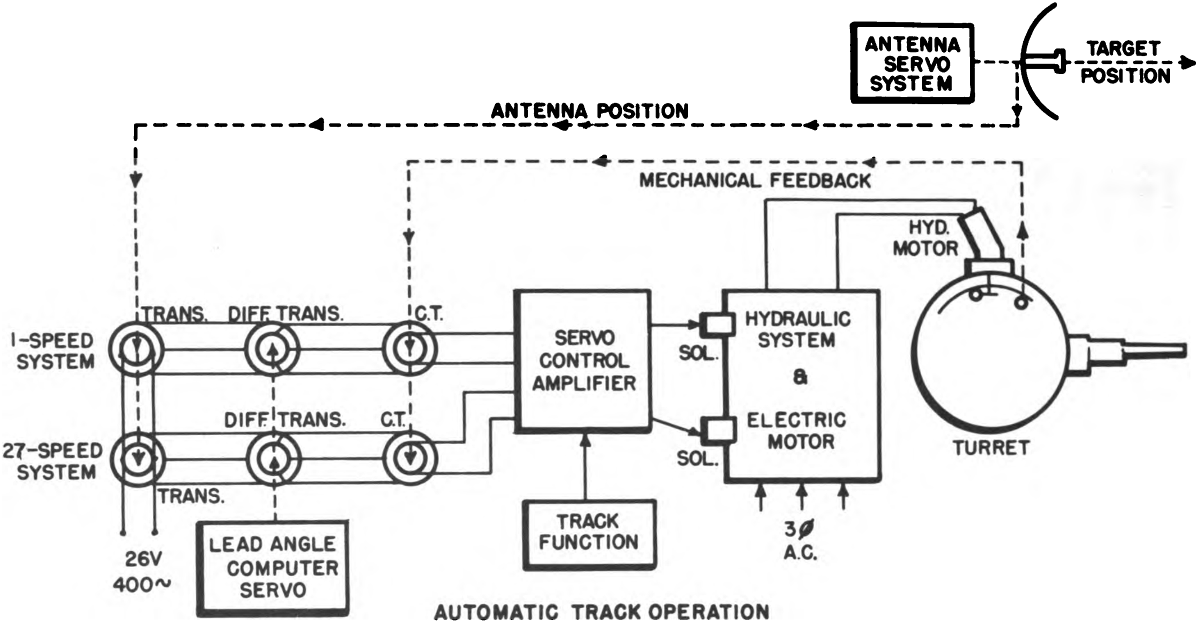


Figure 6–17.—Two-speed synchro system.

Referring to figure 6–17, it should be noted that a 1-speed synchro is paralleled by a 27-speed synchro. The 27-speed synchro generator will rotate 27 degrees for each degree of rotation of the antenna scanner and 1-speed synchro generator. For detailed explanation of a multi-speed synchro system, refer to chapter 5 of this course.

The output of each synchro generator is fed to its respective synchro differential generator where the necessary lead angle is inserted by the computer. This corrected position information is now supplied to the 1- and 27-speed control transformers where an error voltage is produced. The output error voltages are fed to the servo amplifier for amplification. It should be noted that the two parallel systems have a continuous input from the scanner and an output from each is always present at the servo amplifier.

SERVO AMPLIFIER.—A schematic diagram of a typical servo amplifier is shown in figures 6–18 and 6–20. It should be noted that the amplifier consists of a **COARSE-FINE AMPLIFIER**, a **DEMODULATOR**, an **INTEGRAL NETWORK**, a **DITHER OSCILLATOR**, and a **POWER AMPLIFIER**.

The COARSE-FINE AMPLIFIER, in addition to amplifying the error signal from the 1-speed control transformer, must provide some means of determining which error voltage must be used to control the turret. The system is designed to allow the 27-speed error signal to control the turret when the turret error is less than one degree. This is accomplished by the switching actions of V_{2A} and V_{2B} plus the voltage divider network in the grid circuit of V_3. Before considering an input error voltage, consider the static potentials applied to V_2. The plate of V_{2A} and the cathode of V_{2B} are not at zero potential while the cathode of V_{2A} has approximately positive 4 volts applied and the plate of V_{2B} has approximately negative 4 volts applied.

The input stage V_1 is isolated from the remainder of the circuit as long as V_{2A} and V_{2B} are not conducting. This allows the error signal from the 27-speed control transformer to be amplified and a portion of it applied to the demodulator. However, if the amplified 1-speed error signal developed across R_3 exceeds approximately 8 volts

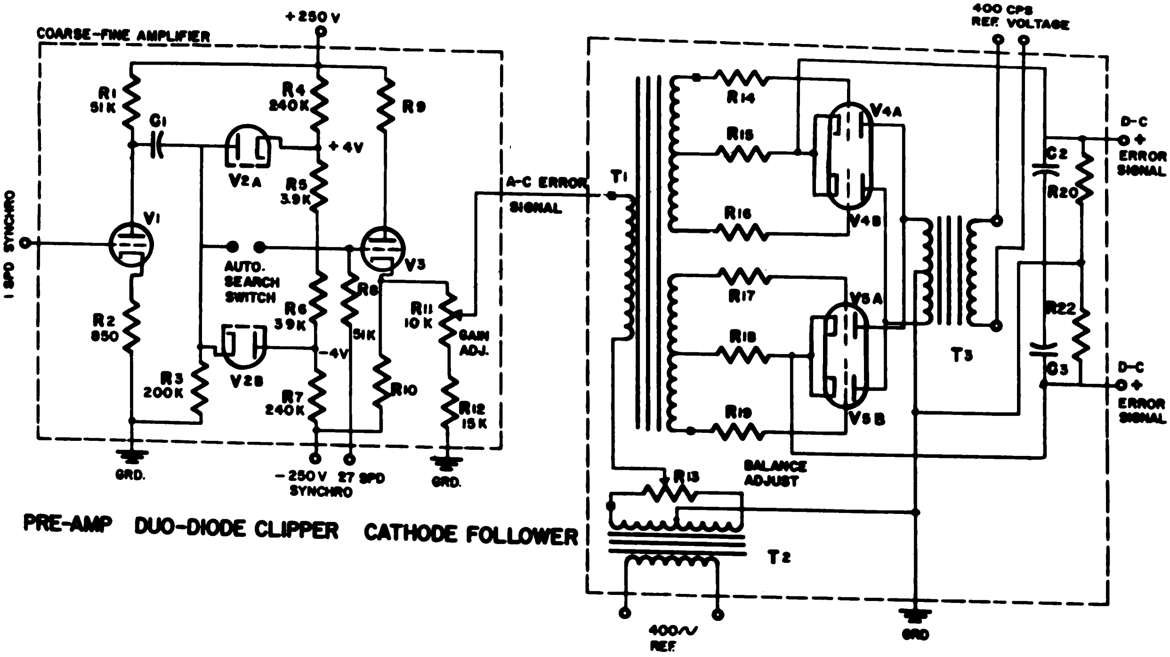


Figure 6–18.—Servo amplifier—coarse-fine amplifier and demodulator.

peak to peak, V_{2A} and V_{2B} will conduct on alternate half cycles. Once this condition exists, the 27-speed error signal is attenuated due to the low impedance path, formed by V_1, V_{2A}, and V_{2B}, between the grid of V_3 and ground while the amplified 1-speed error signal is impressed upon the grid of V_3, thus taking control.

The output of the coarse-fine amplifier is taken from the cathode of V_3 and developed across R_{11} and R_{12}. The potentiometer R_{11} is a gain control and determines the output voltage of the amplifier with a specified input error signal. The automatic search switch, located in the grid of V_3, is provided to couple the 1-speed error signal directly from the first amplifier stage to the grid of V_3 during the automatic search mode of operation. It also provides a path for attenuating the 27-speed error signal whereby the 1-speed error signal will retain control regardless of its amplitude.

The purpose of the DEMODULATOR is to convert the a-c error signal into a d-c voltage. The output of the coarse-fine amplifier is coupled to the demodulator by T_1. It should be noted that one primary lead is connected to the balance control R_{13}. The purpose of the control is to insure that there is no output from the servo amplifier when there is a zero error signal. For a detailed explanation on its operation, refer to chapter 5 of this course.

The secondary winding of T_1 is center tapped, causing an a-c error voltage of equal and opposite polarity to be applied to the grids of the demodulator tubes V_4 and V_5. The reference voltage is applied to the plates of V_4 and V_5 from the secondary winding of transformer T_3. The error signal voltage across the two secondary windings of T_1 are then either in phase or 180 degrees out of phase with the reference voltage.

Study the synchrogram shown in figure 6–19 noting the grid and plate voltages and their resulting output. When there is no error signal applied, the two demodulator tubes conduct equally and the voltage difference between the ends of resistors R_{20} and R_{22} is zero.

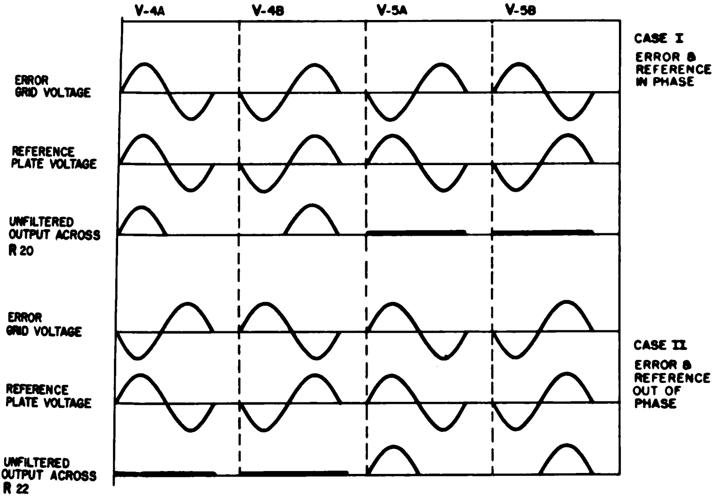


Figure 6—19.—Synchrogram of waveforms in the demodulator.

When the error voltage and reference voltage are as shown in case I, conduction of V_{4A} is increased during the first half cycle and V_{4B} is increased during the second half cycle. It should also be noted that conduction of V_{5A} and V_{5B} is reduced since a negative error signal is applied to the grid of each tube while the plate is positive. This results in an increased positive potential at the top of R_{20} and a reduced positive potential at the bottom of R_{22}, thus giving a push-pull output.

With a 180-degree reversal of the error signal as shown in case II, V_{5A} and V_{5B} increase conduction while the conduction of V_{4A} and V_{4B} is reduced. The voltage at the top of R_{20} is now reduced from its zero error voltage condition and the voltage at the bottom of R_{22} is increased. Capacitors C_2 and C_3 filter the rectified output so that the output from the demodulator is essentially a d-c voltage with a magnitude proportional to the angular difference between the actual and desired position of the turret. It should be remembered that the amplitude of output from the demodulator is the voltage difference between the two output points since both points are positive with respect to ground.

The d-c voltage output of the demodulator is fed through an INTEGRAL NETWORK whose function is to reduce the response time of the servo system. (See fig. 6–20.) For a detailed discussion on its operation, refer to chapter 5 of this course.

The modified d-c output is combined with a DITHER

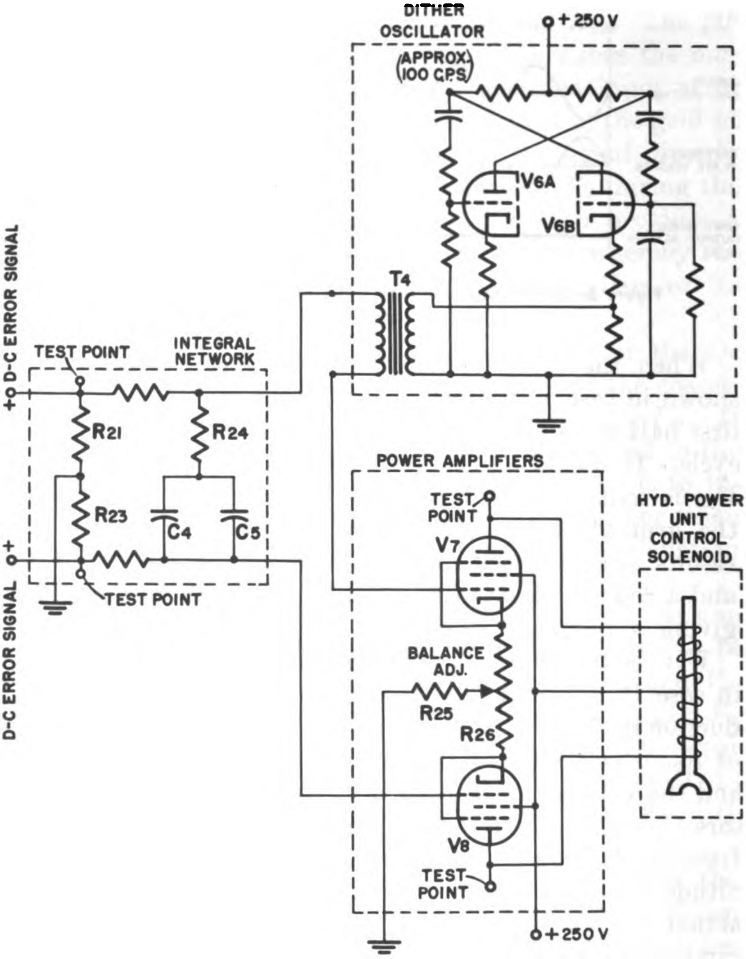


Figure 6–20.—Servo amplifier—integral network, dither oscillator, power amplifier.

OSCILLATOR output voltage. One d-c output of the network is fed directly to the grid of V_8 while the other d-c voltage is applied to the grid of V_7 through the secondary of the dither transformer T_4. Another voltage, called the dither voltage, is added to the error signal applied to the grid of V_7. Before going into the operation of the power amplifier, let us examine the dither circuit. The dither oscillator produces a low frequency output of sufficient amplitude to overcome the static friction in the solenoids and sleeve-valve pump linkage of the turret. Since the frequency of the dither signal is much higher than any that the turret is able to follow, the system is maintained in a state of readiness, thus reducing the dead zone for small angles.

The POWER AMPLIFIER uses two pentode stages connected in push-pull. An unbypassed cathode resistor is utilized to couple the input signal from one stage to the other. The balance control R_{25} is used to balance the plate currents and is adjusted with no error voltage applied to either grid. The stages are designed to saturate for an error signal of one-half degree, so that for large angles of error they deliver constant current. The outputs from the plates of V_7 and V_8 are applied to the load coils of the elevation differential solenoids. The solenoids present a low resistance to the output stage for maximum current. B plus (250 volts) for the power-amplifier plates is applied through the center tap of the solenoid.

A brief summary of the action of the power amplifier is: An error angle produces a voltage input to the d-c power amplifiers. They develop a d-c differential current in the solenoids, the direction of which is determined by the required direction of motion. The magnitude of the current is proportional to the angular difference between the actual turret position and the desired turret position.

HYDRAULIC SYSTEM.—Before going into the operation of the HYDRAULIC SYSTEM, let us briefly review its function. As shown in figure 6–16, the hydraulic system performs the function of the output member of the complete servomechanism. The hydraulic system, like the torque amplifiers studied earlier in this chapter, supplies the necessary power to perform the work of positioning the load. To accomplish this it must convert a constant speed mechanical rotating motion into hydraulic power and reconvert it into mechanical motion.

A pictorial diagram is shown in figure 6–21 of a complete hydraulic system used to position a turret. The main components (1, 2, 3, and 4) and their function are as follows:

1. **GUN TURRET WITH ITS AZIMUTH SECTOR AND ELEVATION SEGMENT GEARS.** The azimuth sector and elevation segment gears are used to convert the output of the hydraulic motors into turret rotation.

2. **AZIMUTH HYDRAULIC MOTOR.** The azimuth motor and its gearbox convert hydraulic power into mechanical rotation to be applied to the turret's sector gear.

3. **ELEVATION HYDRAULIC MOTOR.** The elevation motor and its gearbox convert hydraulic power into mechanical rotation to be applied to the turret's gear segments.

4. **HYDRAULIC POWER UNIT.** This unit contains all components necessary to convert electrical energy into hydraulic power. It contains an azimuth hydraulic pump, an elevation hydraulic pump, a hydraulic control system consisting of a solenoid and power piston for each of the two pumps, a replenishing system to supply low pressure fluid to the power pistons and pumps, and a three-phase electric motor supplying the necessary power to drive the pumps.

The scope of this chapter limits the explanation of the operation of the hydraulic system to the complete system. For a detailed discussion on the operation of hydraulic motors and pumps, refer to *Basic Hydraulics*, NavPers 16193, pages 249 to 268. However, to facilitate understanding of the complete system the basic components will be discussed briefly.

The **HYDRAULIC PUMP** is a variable displacement Vickers axial piston pump known as the "A"-end. Its output is determined by the number of degrees the cylinder block is tilted to either side of a neutral position while the direction of flow of the output is determined by which side of the

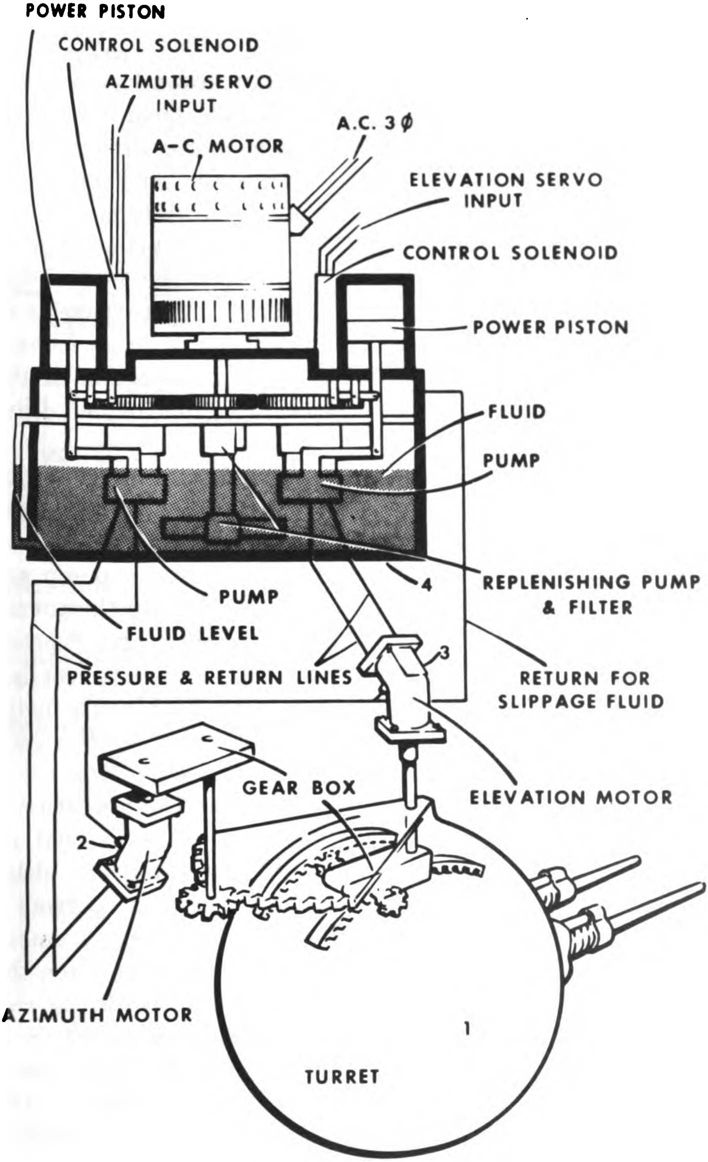


Figure 6–21.—Complete hydraulic turret system.

neutral position the cylinder block is tilted. The pump is rotated at a constant speed by the three-phase motor powering the hydraulic unit.

The FIXED DISPLACEMENT HYDRAULIC MOTOR known as the "B"-end, is driven by fluid delivered from the pump through the connecting tubing. The motor drive shaft is set at a fixed angle to the cylinder block; and because of this fixed angle, the motor requires a definite quantity of fluid for each revolution it makes. The direction of rotation is automatically reversed whenever the flow of hydraulic fluid from the pump is reversed. An increase in the flow of fluid from the pump will result in an increase in the speed of the motor. Thus, the operation of the motor is controlled directly by the variation of fluid delivered to it by the pump.

A REPLENISHING SYSTEM is used in a hydraulic system of this type as the motor must respond to the pump instantaneously from the standpoint of speed of rotation and reversal of rotation. To accomplish this, the pump and motor, as well as the hydraulic lines connecting them, must be kept full of hydraulic fluid at all times. This function is performed by the replenishing pump, which is usually a small gear type pump driven directly by the electric motor. The replenishing system also supplies fluid to the servo control system for the operation of the power piston.

The HYDRAULIC CONTROL SYSTEM controls the operation of the hydraulic system. It should be remembered that the volume of hydraulic fluid moved by the pumps is determined by the amount of displacement of the pump from its center or neutral position. Naturally, a substantial amount of force will be required to displace these pumps when they are working under pressure, since pressure tends to right the pumps and return them to a neutral position where no fluid will be circulated through the system. This condition is overcome by a servo control valve assembly connected by mechanical linkage to each pump yoke assembly. As shown in figure 6–22, each servo control valve assembly consists of a power piston, a follow valve, and sleeve in

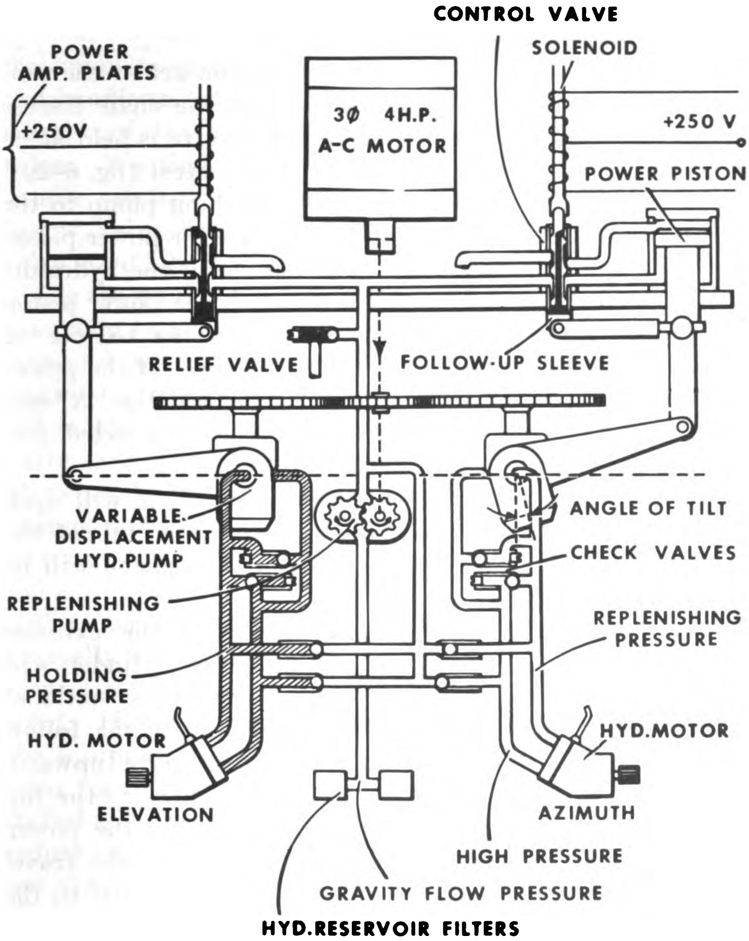


Figure 6–22.—Hydraulic power unit schematic.

which the follow valve operates. Each power piston is connected by linkage to a motor yoke and a follow valve sleeve. The follow valve is operated by the output of the servo control amplifier that is fed to the solenoid. The solenoid moves the follow valve which, in turn, causes the power piston to move proportionally, thus tilting the pump from its neutral position. The power piston is operated by hydraulic pressure supplied by the replenishing pump and is controlled by the follow valve.

Since the follow valve and power piston act as the controlling units for the hydraulic system, we shall discuss their operation in detail. If the follow valve is held at its center position as shown in the azimuth control (fig. 6–22), fluid pressure supplied from the replenishing pump to the underside of the power piston cannot force the power piston to move upward, since there is no escape for the hydraulic fluid which is trapped above the piston. The power piston is, therefore, kept in center position by the balance of hydraulic forces above and below the piston. If the power piston is held in center position, it will hold the "A"-end yoke in center position since the two are connected mechanically.

When the follow valve is moved upward, it will open ports, allowing additional fluid to flow to the top of the power piston. When this occurs, the power piston will be forced downward.

NOTE: Although the top and bottom of the cylinder have the same pressure per unit area, the cylinder will be forced downward due to the larger cross sectional area of the top side. As it moves downward, the follow valve sleeve which is linked to it will move upward, closing off the ports through which fluid flows to the top of the power piston. By this action, travel of the power piston is limited to an amount proportional to the travel of the follow valve. Therefore, the amount of tilt to the "A"-end yoke is determined by the position of the follow valve, since the "A"-end yoke only moves far enough to supply the amount of pumping action required, as determined by the position of the gunner's control.

When the follow valve is moved downward, it will open ports, allowing the fluid at the top of the piston to be forced out as additional fluid forces the piston upward. The upward motion of the piston causes the follower sleeve to move downward, closing off the ports through which fluid was allowed to escape from the top of the power piston.

To insure an understanding of the complete electrohydraulic system, we shall trace an input signal through the complete operation. A movement of the gunner's control handle in the vertical plane will cause a change in the current of the solenoid controlling the elevation follow valve. We shall assume that the motion of the control handle resulted in an error signal that would force the follow valve downward. The downward motion of the valve would allow the power piston to be forced upward tilting the pump yoke from its neutral position and causing the pump to increase its pressure in one of its lines. This increased pressure and flow will cause the motor to rotate until it has positioned the turret, canceling the error signal. When the error signal is canceled, the solenoid, follow valve, and pump are returned to their neutral position allowing the system to remain at rest until there is further change in the gunner's control handle.

Maintenance

The maintenance of an electrohydraulic system will normally be accomplished by a series of inspections. These inspections will necessarily differ with the type of equipment. However, the *Handbook of Service Instructions* for the equipment and the *Handbook of Maintenance Instructions* for the type of aircraft in which the equipment is installed will specify the procedure for maintenance. This procedure may be supplemented by squadron instructions. It is not the intention of this chapter to establish the requirements for maintenance of a particular system, but to discuss the adjustments and basic maintenance required for a basic electrohydraulic servomechanism. The maintenance of an electrohydraulic system may be divided into two sections, ELECTRICAL (and/or electronic) and HYDRAULIC.

HYDRAULIC MAINTENANCE.—The maintenance of the hydraulic system is limited for the Aviation Fire Control Technician due to the lack of training and special tools and equipment required for hydraulic maintenance. However, make periodic checks to insure that the level of hydraulic fluid in the power unit is within the prescribed limits; inspect all hydraulic lines for leaks, dents, short bends, and other damage; and check the hydraulic power unit for indications of leaks around gaskets and tube fittings. Any discrepancies found should be reported and proper steps taken to rectify them.

In addition to the hydraulic components, the mechanical linkage connecting the output of the hydraulic motors to the turret should be checked to insure proper operation. In addition to the mechanical linkage shown in figure 6–21, handcranks are normally provided to allow mechanical positioning of the turret in both the horizontal and vertical planes. This allows the technician to check the mechanical linkage for smoothness of operation, proper action of limit mechanism, and any binding or sticking throughout the mechanical linkage. Any malfunctioning must be reported and proper steps taken to rectify the condition. Lubrication of the linkage should be in accordance with instructions contained in the *Handbook of Service Instructions*.

At the completion of the mechanical and hydraulic check, the turret should be zeroed in both the horizontal and vertical planes and the locking pins inserted. The power cable supplying three-phase power to the hydraulic power unit must be disconnected. ***Caution:*** This must be done immediately after inserting the locking pins to prevent attempted turret operation while the turret is locked. When all defects are rectified and the turret locked in position, begin checking and adjusting the electrical section of the system.

ELECTRICAL MAINTENANCE.—The maintenance of the electrical components of the electrohydraulic system must also be in accordance with the *Handbook of Service Instructions* for the particular equipment. However, the following procedure is applicable to the basic electrohydraulic system discussed earlier in this chapter.

BALANCE ADJUSTMENTS.—The servo control amplifier shown in figure 6–20 contains three adjustments that must be checked to insure proper operation of the equipment.

The first adjustment to be checked is the balance control, R_{26}, located in the cathode circuits of V_7 and V_8. This potentiometer is adjusted to give equal plate current through the power amplifiers with no error voltage applied. The output from the demodulator is eliminated by connecting a shorting lead between the test jacks provided for this purpose. Connect a d-c voltmeter between the power amplifier plates V_7 and V_8, apply power, and adjust R_{26} for a zero voltage reading. After adjusting R_{26}, cut off the power to the amplifier and remove the shorting jumper.

The next adjustment, R_{13}, (fig. 6–18) is necessary to compensate for any unbalance in the demodulator. The output from the coarse-fine amplifier is eliminated by shorting the grid of V_3 to ground. Reapply power to the amplifier and adjust R_{13} for a zero reading of the voltmeter connected between the plates of the power amplifiers. After completing this adjustment, cut off the power and remove the shorting jumper on the grid of V_3.

Before the final amplifier adjustment can be made, the 1- and 27-speed synchros must be checked to insure proper zero setting of their components. This is done by first placing the gunner's control handle at zero degrees in azimuth and elevation and inserting the locking pin. The cable connecting the 27-speed synchro transmitter to its other components must be removed leaving the 1-speed system to drive the amplifier. The equipment is now placed in automatic search operation and a voltage reading is taken on the voltmeter still connected between the power amplifier plates. With the control handle and the turret both locked in their zero position, the voltage reading should be zero. However, a small voltage reading is usually acceptable and this reading must be checked against the acceptable limits established by the service instructions. Should the limit be exceeded, the synchro system will have to be zeroed using the procedure discussed in chapter 5.

After checking the 1-speed system, the 27-speed system must be checked in a like manner. Replace the connector to the 27-speed synchro transmitter and remove the connector from the 1-speed synchro transmitter. After placing the equipment in automatic track mode of operation, the 27-speed system is checked and the voltage reading compared as in the previous case. Reconnect the 1-speed synchro transmitter when completing the check and you are now ready to make the gain control adjustment.

GAIN CONTROL.—The gain control in the servo amplifier is to control the amplification of the error signal. The optimum gain provides for a minimum response time and a maximum stability of the turret. The optimum point will vary with each type of equipment and the gain control must be adjusted in accordance with instructions contained in the *Handbook of Service Instructions*. However, the procedure will normally follow that required for the basic system discussed in this chapter.

The first step is to insure that the hydraulic system has been disabled and apply a static error voltage to the amplifier. The amplitude of the error voltage must be compared with the output of the power amplifiers. This comparison may be made by displacing the turret a specified number of degrees with the handcrank and adjusting the gain control to give a specified voltage reading when taken between the plates of the power amplifiers. To insure proper operation of the system, displace the turret an equal number of degrees from its zero point in the opposite direction and check the voltage reading. This reading should be equal in amplitude but of opposite polarity.

Adjusting the gain control under shop conditions would require the use of test equipment that could furnish an error signal of the correct frequency, amplitude, and phase relationship. Such equipment will normally be provided with each type of turret and instructions for its operation will be contained in either the *Handbook of Service Instructions* for the turret or an instruction book for the test equipment. The testing principle is the same as above.

It should be remembered that the azimuth and elevation channels of the turret system are paralleled and all the above adjustments must be performed in both channels for the equipment to operate properly.

QUIZ

1. A torque amplifier is a device used for increasing the power output
   a. while increasing the quality of the input
   b. without appreciably increasing the quality of the input
   c. while increasing the quantity of the input
   d. without appreciably increasing the quantity of the input

2. In a mechanical torque amplifier (fig. 6–2), the output power is derived from
   a. control clutch A
   b. control clutch B
   c. input detector
   d. the constant speed drive motor

3. In a mechanical torque amplifier, during the static balanced condition,
   a. the cam follower is located halfway up the cam inclined plane
   b. both control clutches are engaged
   c. the constant speed motor is turned off
   d. the common output gear is disengaged from the clutch output gears

4. An electrical torque amplifier, with no electrical power applied, is
   a. capable of transmitting unlimited amount of torque
   b. not capable of transmitting a limited amount of torque
   c. capable of transmitting a limited amount of torque which is normally not effective
   d. capable of operating properly because the electric motor operates independently of power applied to torque amplifier

5. Hunting in a servo system occurs when
   a. servo loop gain control is set too low
   b. servo loop gain control is set too high
   c. excessive damping is used
   d. input signal is varying

6. A demodulator
   a. converts the d-c error signal to a.c.
   b. amplifies the d-c error signal
   c. converts the a-c error signal to d.c.
   d. accepts quadrature signals

7. The lead integral network in a servo loop corrects for phase shift through the amplifier, because without it the
   a. servomotor would be faulty in response
   b. servomotor would run too fast
   c. servomotor would not run
   d. reference voltage would be incorrect

8. The main components of the antenna servo system used during search operation are the error detector and its
   a. 50-cycle voltage source, servo amplifier, servomotor, and data transmission system
   b. 50-cycle voltage source, servo amplifier, and servo hunter
   c. 400-cycle voltage source, servo amplifier, and servomotor
   d. 400-cycle voltage source, servo amplifier, servomotor, and data transmission system

9. The main components of the antenna servo system employed during track operation are the radar receiver and
   a. 50-cycle amplifier, servo amplifier, and servomotor
   b. 50-cycle amplifier, servo amplifier, servomotor, and 50-cycle spin generator
   c. 40-cycle amplifier, servo amplifier, and a servomotor
   d. 40-cycle amplifier, servo amplifier, servomotor, and a 40-cycle spin generator

10. The elevation scan generator is utilized during
   a. all modes of operation
   b. track only
   c. search and track
   d. automatic search only

11. The function of the 50-cycle spin generator in the antenna servo system is to furnish a reference voltage for the
    a. radar receiver during search operation
    b. demodulator during search operation
    c. demodulator during track operation
    d. modulator during operation

12. The disadvantage of a complete hydraulic turret system is that
    a. it is not easily adapted to remote operation
    b. it cannot meet large power demands for long periods of time
    c. time of response excessively lags the given order
    d. the system is bulky and weighty

13. The purpose of the balance control in the demodulator of the turret control system is to
    a. adjust the 400-cycle reference voltage
    b. insure there is no input to the servo amplifier when there is zero error signal
    c. insure there is maximum output to the servo amplifier when there is a zero error signal
    d. adjust the 50-cycle reference voltage

14. The purpose of the "dither oscillator" in the turret control system is to produce a
    a. high frequency output of sufficient amplitude to overcome static friction in the solenoids and sleeve valve pump linkage of the turret
    b. low frequency output of sufficient amplitude to overcome static friction in the solenoids and sleeve valve pump linkage of the turret
    c. low voltage output to the power amplifiers
    d. high voltage output to the power amplifiers

15. The magnitude of the current output of the d-c amplifiers to the solenoids of the turret control system (fig. 6–20) is proportional to the angular difference between
    a. actual turret position and actual target position
    b. desired turret position and actual target position
    c. desired turret position and predicted target position
    d. actual turret position and the desired turret position

16. The hydraulic pump in a complete hydraulic turret system is a
    a. variable displacement axial piston pump known as the "A"-end
    b. variable displacement axial piston pump known as the "B"-end
    c. constant displacement axial piston pump known as the "A"-end
    d. constant displacement axial piston pump known as the "B"-end

CHAPTER 7

DATA SENSING DEVICES

The main function of the fire control computer and its associated devices is the solution of the fire control problem to insure effective delivery of the firepower of an aircraft whether it be bullets, rockets, guided missiles, or bombs. This solution is dependent on many factors, such as ballistics of the projectile, air pressure, air temperature, relative motion of target, and wind. (NOTE: The solution of the fire control problem is discussed in detail in chapter 3 of *Aviation Fire Control Technician 3*, NavPers 10388.)

Some of the required data, such as ballistic information, is supplied the computer by fixed or hand inputs. Other factors, such as range, range rate, and relative motion, are continuously changing and must be fed into the computer as the changes occur. For the purpose of this course, devices that detect and transmit data for the solution of the fire control problem will be called DATA SENSING DEVICES. Some of the data sensing devices most frequently encountered in fire control equipment will be discussed in this chapter.

PRESSURE DIAPHRAGMS

In the solution of the fire control problem, a factor affecting the time of flight of a projectile or time of fall of a bomb is air density. Since air density varies directly as air pressure and inversely as air temperature, fire control equipment must include devices for their measurement. The device used for determining air pressure may be referred to as aneroid, diaphragm, or pressure bellows. However, for the purpose of this course it will be referred to as a diaphragm.

Since the diaphragm device to be discussed in this section will primarily be concerned with the measurement of air pressure, we shall first consider the properties of air. The atmosphere in which we live and breathe is the envelope surrounding the earth that extends upward to about 200 miles above the earth's surface. It is a mixture of gases, and the weight of these gases which compose the atmosphere exerts a pressure against the surface of the earth. Thus, any area on the earth supports the weight of a column of air which extends above it for a distance of 200 miles, or the depth of the atmosphere.

By direct measurement it has been found that an area of one square inch at sea level supports a vertical column of air that weighs 14.7 pounds. At higher altitudes this force is less, because the column of air supported is shorter. Therefore, the pressure exerted by the weight of the atmosphere on any area grows correspondingly smaller with any increase in altitude because of the lessened weight of the column of air that rises vertically above it.

Another important factor affecting the atmosphere is the temperature. The sun sends out heat and light radiation. This radiation warms the air and, because it is warmed, its density is less, so it will rise. In rising to a region of less pressure, air will expand. When air expands, its temperature drops. Because of this expansion and the greater distance from the secondary source of heat on the earth, the temperature is less at higher altitudes in the troposphere.

For convenience a standard atmosphere has been adopted. This assumes certain values of temperature and pressure for various altitudes. With the temperature and pressure decided upon, the density at various altitudes is determined. The standard temperature at sea level is 59° F., while the pressure in inches of mercury is 29.92. NOTE: The 29.92 inches of mercury is taken from a mercurial barometer and is equivalent to 14.7 pounds per square inch air pressure.

Basic Pressure Diaphragm

A basic diaphragm used to determine air pressure is shown in figure 7–1. It consists of a diaphragm and the necessary linkage to either position a pointer or transmit the information to other units for further computations.

The diaphragm looks like the case of a pocket watch that has been corrugated with circular ridges and hollows. It is sealed and has a tendency to collapse or expand, depending on the relation of the pressure sealed inside the diaphragm to the existing pressure surrounding the diaphragm.

Note that the inner side of the diaphragm is fixed to the frame of the device, and that the outer side is attached to a post which is linked to the pointer-operating mechanism. The case of the diaphragm pressure-measuring device is usually sealed airtight. The pressure you wish to meas-

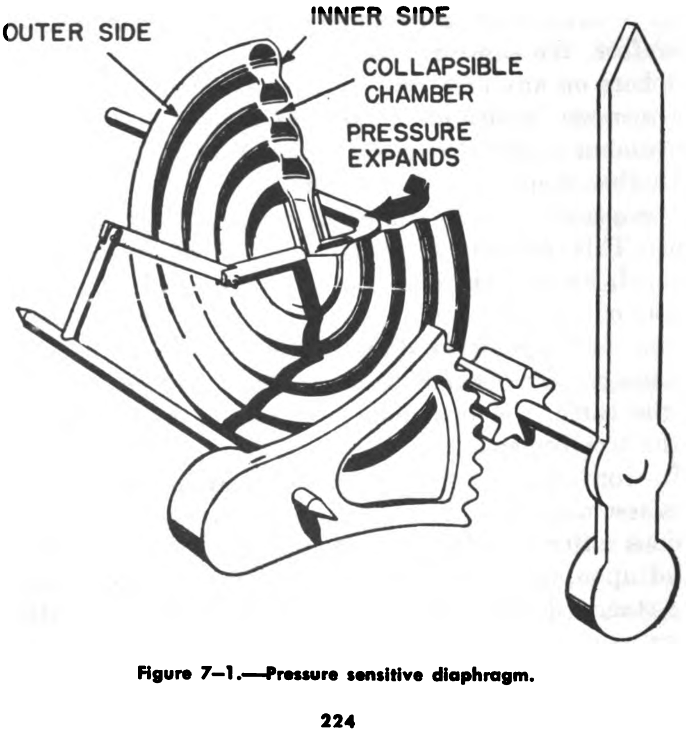


Figure 7–1.—Pressure sensitive diaphragm.

ure is introduced into the sealed case through a tube connection.

As the pressure in the casing increases, the diaphragm is compressed and its outer side is pushed inward. If the pressure in the casing is decreased, the pressure inside the diaphragm pushes the outer side of the diaphragm away from the inner side. In either circumstance, the post moves with the motion of the outer side of the diaphragm, and causes the pointer needle to swing in the proper direction over the instrument dial.

Applications of Pressure Diaphragms

Air density compensator unit.—The air density compensator unit provides the fire control computer with information on air pressure which, in turn, combines this information with temperature to compute air density. The unit consists of a pressure diaphragm and its associated mechanical and electrical linkage for the transmittal of this data.

The compensator unit is essentially a standard altimeter which has been modified by adding a tapped resistance winding with fixed contacts and a sliding contact attached

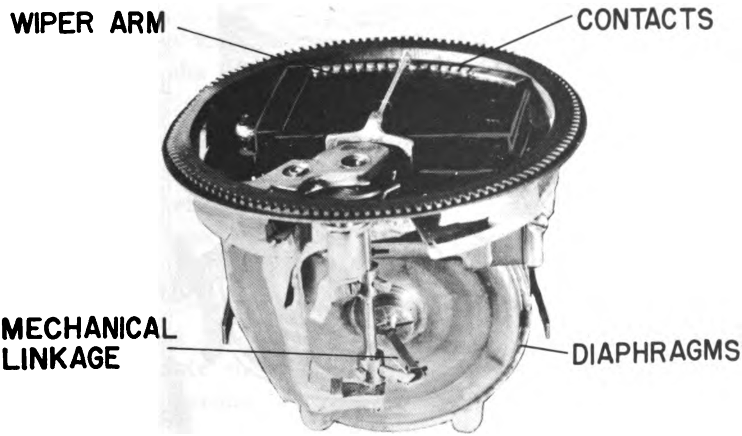


Figure 7–2.—Typical air density compensator.

to a wiper arm. (See fig. 7–2.) The wiper arm is moved by the barometric element of the altimeter so that the active resistance of the unit varies with altitude.

Absolute-pressure pickup.—Absolute-pressure pickup is a device for determining air pressure relative to a predetermined standard. As shown in figure 7–3, the absolute-pressure pickup consists of two pairs of pressure diaphragms linked by a rocking shaft. Attached to the rocking shaft is a contact arm which slides across a wire-wound resistor, as atmospheric pressure changes cause the dia-

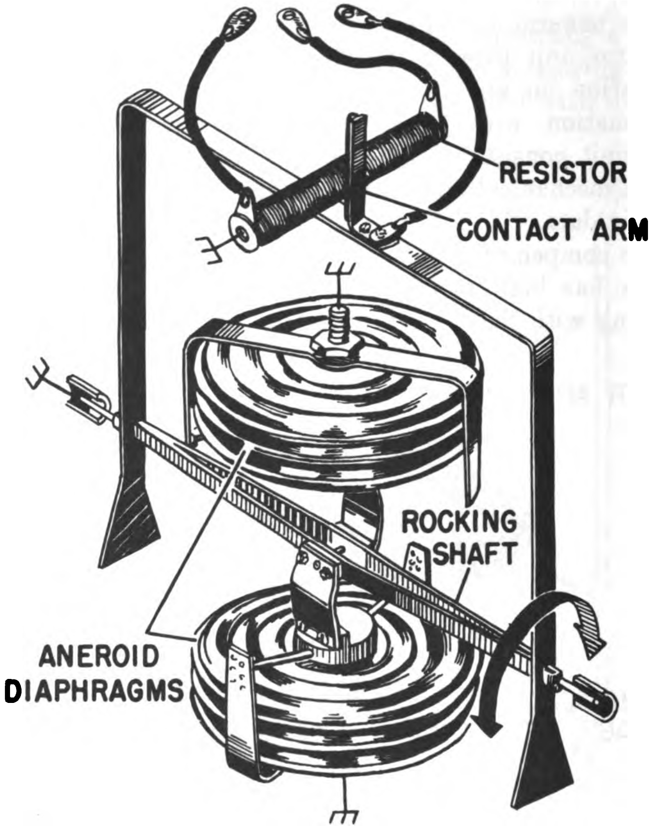


Figure 7–3.—Typical absolute-pressure pickup device.

phragms to expand or contract. It should be noted that the diaphragms are connected to provide a push-pull action.

The resistance of the device shown increases directly with the pressure. A typical unit is calibrated to give a resistance of approximately 2,000 ohms when indicating 31 inches of mercury.

TRUE AIRSPEED TRANSMITTER.—As pointed out previously, the solution of the fire control problem is dependent on the true airspeed of the gun platform. True airspeed cannot be measured directly. It must be computed, based on static air pressure (altitude), temperature, and impact air pressure. A typical true airspeed transmitter capable of determining all three variables is shown in figure 7–4. Each of the three variables is represented by a proportional pressure that is applied to one of the three pressure diaphragms. The airspeed diaphragm is expanded or contracted in accordance with pitot pressure supplied by the aircraft pitot-static system. Atmospheric (static) pressure from the pitot-static system controls the altitude diaphragm. Liquid pressure actuates the temperature diaphragm providing a temperature correction. NOTE: Temperature devices will be discussed later in this chapter.

As indicated in figure 7–4, the altimetric slide moves horizontally in proportion to altitude and vertically in proportion to airspeed. The intermediate rocking shaft linked with the slide is thereby rotated a fraction of a revolution as airspeed changes. The amount of rotation is controlled by altitude, which determines the effective length of the altimetric slide. For example, at very low altitudes the effective slide length is a near-maximum and a given airspeed produces a minimum rotation of the intermediate rocking shaft. At very high altitudes the effective length of the altimetric slide is a near-minimum and the given airspeed produces a maximum rotation of the intermediate rocking shaft. The net amount of rotation of the intermediate rocking shaft represents airspeed, and is proportional to the difference between pitot pressure and static pressure.

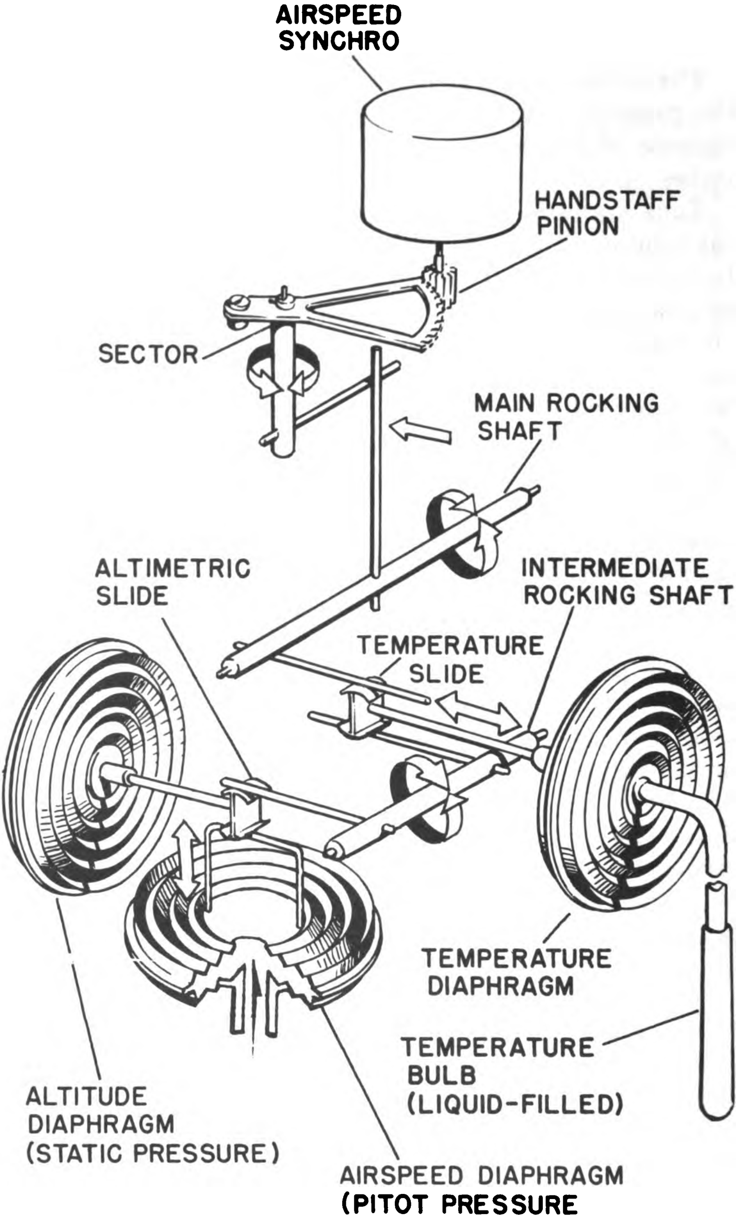

AIRSPEED SYNCHRO
HANDSTAFF PINION
SECTOR
MAIN ROCKING SHAFT
ALTIMETRIC SLIDE
INTERMEDIATE ROCKING SHAFT
TEMPERATURE SLIDE
TEMPERATURE DIAPHRAGM
TEMPERATURE BULB (LIQUID-FILLED)
ALTITUDE DIAPHRAGM (STATIC PRESSURE)
AIRSPEED DIAPHRAGM (PITOT PRESSURE

Figure 7–4.—Typical true airspeed transmitter.

Airspeed, indicated by the position of the intermediate rocking shaft, must be corrected for free air temperature to obtain true airspeed. Air temperature data is provided by the liquid-filled temperature bulb, which is exposed to the external atmosphere through an opening in the skin of the aircraft. The temperature of the air around the bulb controls the pressure of an enclosed liquid which, in turn, transmits the pressure to the temperature diaphragm. Rotation of the main rocking shaft is the result of the combined action of the three pressure diaphragms. The position of the main rocking shaft represents true airspeed within the limits of the equipment.

Since data can be transmitted from one location to another more effectively with the use of an electrical device, the motion of the main rocking shaft is transmitted to a synchro transmitter shaft by means of a sector gear and pinion assembly. The a-c output of the synchro transmitter is fed to the fire control computer.

Maintenance

Maintenance of devices utilizing pressure diaphragms by the Aviation Fire Control Technician is normally limited to performance checks and replacement of defective units. The *Handbook of Service Instructions* for the particular equipment will normally provide a procedure to be used in performing the various checks. Units requiring repair should be packaged in accordance with instructions and sent to the proper repair activity.

TEMPERATURE DETECTING DEVICES

As pointed out in the previous section of this chapter, air temperature must be considered in the solution of the fire control problem. Also, changes in electrical and electronic component values due to changes in temperature must be detected and some means of compensation provided. There are two types of temperature detecting devices to be discussed in this section. They are the LIQUID TEMPERATURE BULBS and RESISTIVE TEMPERATURE DEVICES.

Liquid Temperature Bulb

This device may be used in various pieces of aviation fire control equipment for detecting or measuring outside air temperature. Its output may be applied directly to a fire control computer or may be combined with the output of other data sensing devices before being fed to a computer. Typical of the latter application is the true airspeed transmitter just studied. Referring to figure 7–4, it should be noted that temperature is combined with the output of two other devices, and the resulting true airspeed is transmitted to the fire control computer.

A liquid temperature bulb device consists of a bulb, capillary tube, and diaphragm—all of which are filled with a liquid. The device operates on the principle that the liquid has a positive coefficient of expansion; that is, the liquid will expand with an increase in temperature and contract with a decrease in temperature. Since the bulb is placed on the outside of the aircraft where it is exposed to the outside temperature, a change in temperature will change the volume of liquid, thus causing the liquid to flow through the capillary tube changing the displacement of the diaphragm. Mechanical linkage is provided to transmit this change in displacement (change in temperature) to the computing device utilizing this temperature information.

Resistive Temperature Devices

Resistive temperature element.—This device also is used to provide true airspeed computer information on the ambient temperature of the air through which the aircraft is traveling. The major components of the unit are the housing, diffuser, temperature coil, and insulator assembly. The temperature coil and insulator assembly are mounted inside the cylindrical housing. The housing, which has a hole in the front end to allow air to contact the temperature sensitive components, is mounted on the surface of the aircraft. The diffuser is a metal, double-walled cover with holes in the forward end and side wall. It shields the enclosed temperature coil from radiation, yet allows sufficient air to enter to provide accurate temperature information.

The principle of operation of this type of temperature element is based on the fact that metals change their electrical resistance with changes in temperature. In most metals the electrical resistance varies directly with temperature. Thus, a temperature element constructed with a metallic heat sensitive element that has a definite resistance for each temperature of its operating range could easily be calibrated to provide accurate temperature information to a computer.

A typical resistive temperature element is shown in (A) of figure 7–5. Its associated electrical circuit is shown in (B) of the same figure.

TEMPERATURE COMPENSATING DEVICE.—The purpose of a temperature compensating device is to provide automatic correction for errors generated in a computer which are caused by changes in temperature within the computer. The temperature compensating device consists of a parallel negative-coefficient resistor (commonly called a THERMISTOR) which is connected in a circuit in a manner to provide compensation in the circuit for a change in temperature.

A typical application of a temperature compensating device can be found in a computing sight, and functions in the following manner:

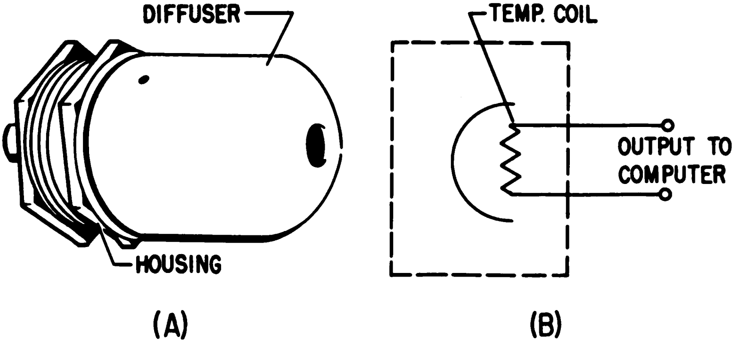


Figure 7–5.—Temperature elements.

With an increase in temperature inside the sight, the resistivity of the aluminum dome in the gyro will increase and eddy currents decrease, thus reducing the restraining force on the gyro. Without the temperature compensating unit, this would result in a larger lead angle being generated. However, as the temperature increases, the resistance of the compensating circuit will decrease and allow more current to flow in the range coils.

This increase in current will increase the restraining force due to the decrease in eddy currents in the dome. Conversely, with a decrease in temperature inside the sight, the resistivity of the dome will decrease, eddy currents will increase, the resistance of the compensating circuit will increase, and range-coil current will decrease so as to compensate for the increase in eddy currents in the dome. Thus, as the resistivity of the dome varies with changes in operating temperature, the temperature compensating circuit provides the range coils with varying amounts of current to keep the generated lead angles at the proper values.

As an Aviation Fire Control Technician, your work on temperature devices will not be extensive. These devices are of relatively simple construction and once any part becomes defective, it is a matter of replacing the complete unit. Most of the work on these devices will be concerned with checking for proper operation and replacement of defective units. Checking procedure will be found in the *Handbook of Service Instructions* for the specific equipment.

ACCELEROMETERS

An accelerometer may be defined as a device or transducer which gives an indication usually in the form of a voltage proportional to the acceleration to which it is subjected. They are utilized in armament control systems to detect and measure acceleration in any desired plane for such purposes as follows:

1. Provide information to the fire control computer,

whereby it may correct for gravity drop of the projectile when the aircraft is performing maneuvers other than straight and level flight.

2. Provide information to the bombing computer to aid in determining the release point during loft and toss bombing runs.

3. Provide information to the gyroscopes used to maintain stable reference platforms to prevent the gyroscopes from precessing on false gravity inputs.

It should be remembered that the use of accelerometers in armament control equipments is not limited to the three previously mentioned applications.

Theory of Operation

Before considering the theory of operation of the accelerometer, let us review Newton's first law of motion. Newton stated in part that every body moving with a constant velocity (hence in a straight line) continues in a straight line until acted upon by an outside force causing it to change its state of motion. The application of this law provides the basic principle on which the accelerometer operates.

Basically, an accelerometer consists of a mass suspended like a free swinging pendulum within a case. When the case and pendulum are traveling at a constant speed the pendulum remains in its center position. However, when the case is accelerated, the pendulum will appear to swing in the opposite direction of the accelerating force. It may also be said that the case tries to outrun the suspended mass, causing a change in the relationship of the mass and case.

In actual practice, the mass is held in its null or zero position with a calibrated spring or springs. To further dampen oscillations, the case is normally filled with a fluid. Since the deflection of the pendulum is proportional to the accelerating force, the amount of deflection (hence the accelerating force) is measured and transmitted to other units for use in the solution of the fire control problem.

Typical Accelerometers

Potentiometer type accelerometer.—This particular type of accelerometer is used in present day aircraft in the solution of loft and over-the-shoulder bombing problems. It measures the G's pulled by the aircraft during the maneuver and aids immeasurably in determining the point of release of armament. It is also used in aviation fire control systems to aid in solving air-to-air gunnery and rocket problems.

Figure 7–6 shows a typical potentiometer type accelerometer that may be encountered by the Aviation Fire Control Technician. It consists of a mass mounted on a vertical shaft. The mass is suspended by means of springs and dampened by a fluid sealed in the case or container. A stationary potentiometer is located within the case with the wiper contact attached to the mass. The wiper contact will pick off a voltage based on the position of the mass. As the aircraft accelerates either positively or negatively in the vertical plane, the mass will move accordingly on the vertical shaft, stretching one of the springs

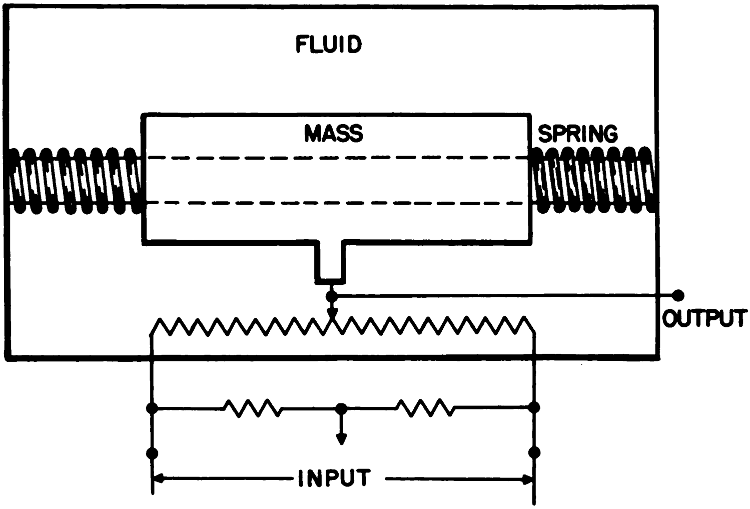


Figure 7–6.—Typical potentiometer type accelerometer.

and compressing the other. In so doing, the potentiometer wiper contact is moved in respect with the potentiometer and automatically picks off a signal proportional to the G's pulled by the aircraft.

E-TRANSFORMER TYPE ACCELEROMETER.—The E-transformer type accelerometer may be found in high altitude horizontal bombing equipment. It is used to detect excessive horizontal acceleration that could cause false gravity inputs to the stabilizing gyroscopes. The normal installation utilizes two accelerometers. On is mounted parallel to and along the PITCH AXIS of the platform to detect excessive accelerations along that axis. The other is mounted parallel to and along the ROLL AXIS of the stabilized platform for the purpose of detecting excessive accelerations along the roll axis.

Basically, this type of accelerometer consists of a mass suspended from a calibrated leaf spring in a manner like a pendulum. The mass is effectively the armature of an E-transformer such as is used as an error detector in a servo system. The mass of the accelerometer is enclosed

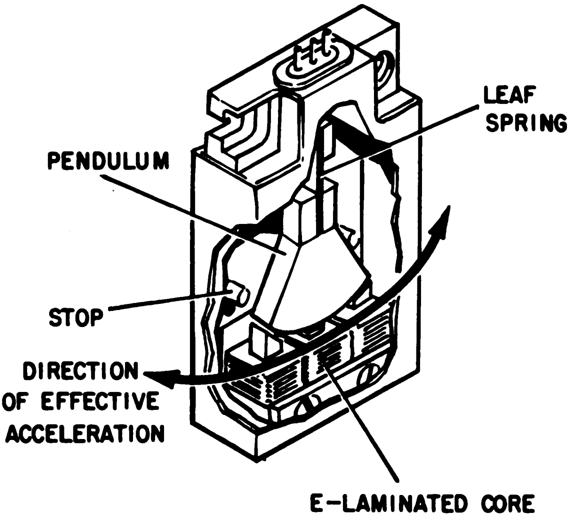


Figure 7–7.—E-transformer type accelerometer.

within a case that is filled with a liquid which helps keep the pendulum from oscillating. The accelerometer is mounted so that acceleration in only the desired plane is detected.

Referring to figure 7–7, it should be noted that when there is no acceleration, the pendulum remains centered and the accelerometer output is zero. However, when there is acceleration, the mass or pendulum swings in the opposite direction of the acceleration causing an output from the E-transformer. Since the amplitude of the pendulum swing is proportional to the amplitude of the acceleration to which it is subjected, the output of the device is indicative of both the direction and amplitude of the acceleration. This output is within the limits of the equipment and is limited by physical stops.

Maintenance

There is normally a minimum of maintenance on accelerometers performed by the Aviation Fire Control Technician. Maintenance will normally consist of performing operating checks as prescribed by the *Handbook of Service Instructions* for the applicable equipment. Defective units should be replaced and forwarded to an overhaul shop where repair can be performed by qualified personnel.

FLUX VALVES

The flux valve is a data sensing device which is sensitive to external magnetic fields. It is employed in conjunction with high altitude radar bombing and navigation equipment to establish a north-south reference. The device senses the earth's magnetic field and produces electrical data having characteristics corresponding to its degree of rotation from magnetic north.

Theory of Operation

The flux valve operates on the same basic principles utilized by saturable reactors discussed in chapter 4 of this course. The device in its simplest form consists of an output winding over a core which is easily saturated and desaturated, and an exciting winding to which an a-c voltage is applied for saturating and desaturating the core. The amplitude of the exciting current is of such a value that the core is saturated only 90 degrees (45 to 135) of each half cycle of input.

Whenever the core is not saturated, the earth's magnetic lines of force near the winding are deflected through the low-reluctance core, as shown in (A) of figure 7–8. This produces a relatively large flux through the core. Whenever the core is saturated, its reluctance is approximately the same as that of air. Therefore, the earth's magnetic lines of force near the winding are no longer deflected to travel through the core. (See (B) of fig. 7–8.)

As long as the core remains saturated or desaturated, no voltage is induced into the output winding by the constant flux. However, when the core has been desaturated and suddenly becomes saturated, the earth's magnetic lines of force, moving out of the core past the turns of the winding, induce a pulse of voltage into the winding. Also, when the core has been saturated and suddenly becomes desaturated, the earth's magnetic lines of force, moving past the turns of the winding and into the core, induce a voltage pulse of opposite polarity into the winding. Thus, the voltage is induced into the output winding only when the flux is changing.

The amplitude of the voltage pulses so developed depends upon the rate of change of flux. Since the exciting current saturates the core at a fixed rate, twice for each cycle, the amplitude of the output voltage will depend on the relationship of the core to the earth's magnetic lines of force. The amplitude of the induced voltage will be greatest when the core of the flux valve is alined with the earth's magnetic field. The polarity of the output voltage when the valve points north is opposite the polarity when the valve points south. When the valve points either east or west, there will be no output voltage, because none of the lines of force cut the turns of the winding. When the valve points in any direction between north and east

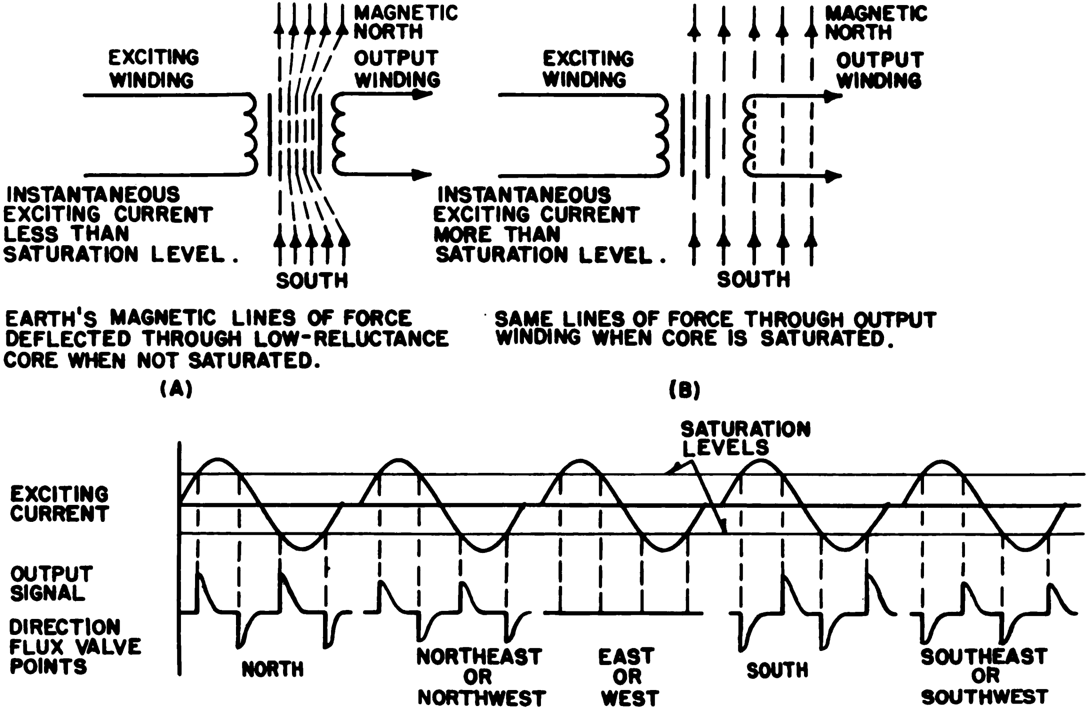

MAGNETIC NORTH
EXCITING WINDING
OUTPUT WINDING
INSTANTANEOUS EXCITING CURRENT LESS THAN SATURATION LEVEL.
SOUTH
EARTH'S MAGNETIC LINES OF FORCE DEFLECTED THROUGH LOW-RELUCTANCE CORE WHEN NOT SATURATED.
(A)
MAGNETIC NORTH
EXCITING WINDING
OUTPUT WINDING
INSTANTANEOUS EXCITING CURRENT MORE THAN SATURATION LEVEL.
SOUTH
SAME LINES OF FORCE THROUGH OUTPUT WINDING WHEN CORE IS SATURATED.
(B)
SATURATION LEVELS
EXCITING CURRENT
OUTPUT SIGNAL
DIRECTION FLUX VALVE POINTS
NORTH
NORTHEAST OR NORTHWEST
EAST OR WEST
SOUTH
SOUTHEAST OR SOUTHWEST

Figure 7—8.—Elementary flux valve.

or between north and west, the polarity of the output is the same as when it is pointing north, but the amplitude of the output is less. The amplitude of the output is then proportional to the cosine of the angle existing between magnetic north and the direction the valve points. When the valve points in any direction between south and east or between south and west, the polarity of the output is the same as when it is pointing south, and the amplitude is proportional to the cosine of the angle between magnetic south and the direction the valve points. (See (C) of fig. 7–8.)

The core of the basic flux valve compass element of the type used in conjunction with the fire control equipment is shaped like an equiangular letter Y as shown in figure 7–9. An output coil is wound around each leg of the core, and one side of each winding is connected to one side of each of the other two windings. The exciting coil is wound on a vertical core at the center of the wye core. The 400-cycle voltage applied to the exciting winding saturates all

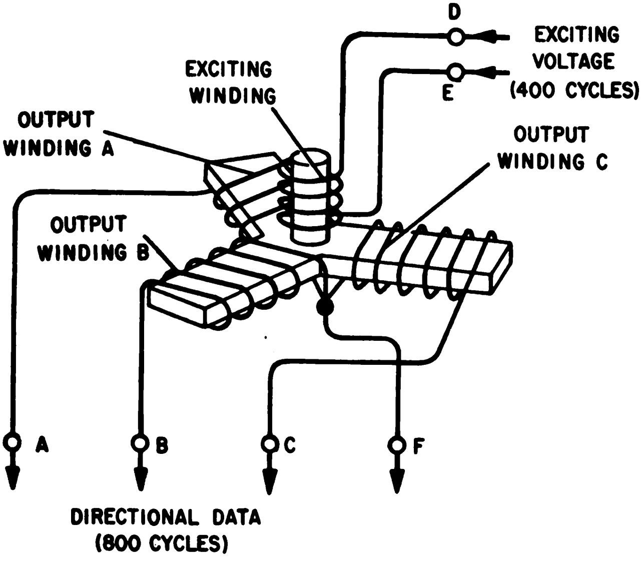


Figure 7–9.—Basic flux valve compass element.

three legs at the same time. The changing flux of the earth's magnetic field induces a voltage into each leg in the same manner that a voltage is induced into the single leg of the elementary flux valve. The amplitude and phase polarity of the voltage induced into each leg depend upon the direction its axis points with respect to magnetic north. When the flux valve compass element is installed in an airplane, the three output signals together constitute electrical data which represents the heading of the aircraft with respect to magnetic north.

This electrical data is similar to the data produced by a synchro transmitter except that it is converted from rotation of the aircraft about its vertical axis instead of from shaft rotations. In a synchro transmitter, the stator windings usually remain in a fixed position, and the magnetic field of the rotor is rotated with respect to the windings. In a flux valve compass element, the magnetic field of the earth remains in a fixed position, and the output windings are rotated with respect to the field when the aircraft changes its heading. The directional data is applied directly to the stator windings of a synchro control transformer.

The use of the Y flux valve compass element with its three outputs results in the cancellation of any voltage induced into the output winding by the primary or exciter voltage. The only voltages present between the three output points are the output signals produced by the earth's magnetic lines of force cutting the turns of the winding. These signals have a frequency of 800 cycles, twice that of the exciting voltage.

The flux valve core and its windings are suspended like a pendulum from a universal joint in a case. This suspension tends to keep the output windings in the horizontal plane when the airplane pitches or rolls. The case is filled with a damping fluid which helps keep the pendulum from oscillating as it swings to the vertical each time the aircraft deviates from level flight.

Maintenance

The maintenance of a flux valve by the Aviation Fire Control Technician is normally limited to making performance checks, replacing defective units, and making various adjustments and alinements.

PERFORMANCE CHECKS.—The performance check is mainly concerned with the individual flux valve units. The flux valve units are used in matched pairs, and the characteristic number stamped on each valve of a pair should be within 5 percent of each other. If they are not, they should be replaced with a pair that is within the specified tolerance.

Caution: A flux valve should never be checked with an ohmmeter.

A special test set is used in making the performance check, and the *Handbook of Operating Instructions* should be consulted for proper operation of the set. By means of the test set, it is possible to simulate aircraft headings and observe indications on a meter. At some heading and 180 degrees from that heading the meter should indicate a zero reading. At 90 degrees from each of these headings, the meter should indicate a maximum reading. If neither valve checks out in any one position, both valves should be replaced.

AIRCRAFT ALINEMENT.—The objective of this procedure is to aline the flux valves with the aircraft so that they will accurately detect the heading of the aircraft. All aircraft electrical equipment that will introduce magnetic disturbances should be turned on during the alinement procedure. Specification MIL–C–7834 outlines the procedures to be followed in making this alinement.

Caution: All magnetic objects should be removed from the area of operation and from the clothing of individuals concerned. Nonmagnetic screwdrivers should be used.

INTRODUCTION TO GYROSCOPES

Gyroscopes found in aviation fire control equipment may be classified according to their general use; namely, rate and stabilizing. In this section two types of rate gyroscopes will be discussed. This will be followed by a discussion of stabilizing gyroscopes used both singularly and in multiples of two or three.

However, before we can discuss their application, the basic theory of gyroscope operation must be reviewed. It is recommended that before proceeding further in this chapter, the section entitled "Principles of the Gyroscope" in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388, should be reviewed.

The word GYRO has assumed the same meaning as the word gyroscope due to long established practice and, therefore, is accepted terminology when discussing gyroscopes. Hereafter in this course the term gyro will be used in the discussion of the various gyroscopes and matters pertaining to them.

Elements of Gyros

A gyro may be defined as a disk or rotor mounted to spin rapidly about an axis, and also free to rotate about either or both of two axes perpendicular to each other and the axis of spin.

The gyro shown in figure 7-10 is a basic universally mounted gyro which meets all the requirements of the definition. The components are ROTOR, INNER GIMBAL, OUTER GIMBAL, and BASE or SUPPORT. The three common axes of any gyro are the SPIN, TORQUE or SERVO, and PRECESSION or TILT. The spin axis is, of course, the axis on which the rotor spins. The torque or servo axis is the axis about which the disturbing force is applied whether it is desirable or undesirable. The precession or tilt axis is the axis the gyro moves about as a result of the force applied about the torque axis.

The term gimbal may be defined as a device for permitting a body to incline freely in any direction and retain that position when the support is tipped or repositioned. It should be noted that in figure 7-10 the support may be moved about all three axes without the rotor position being disturbed.

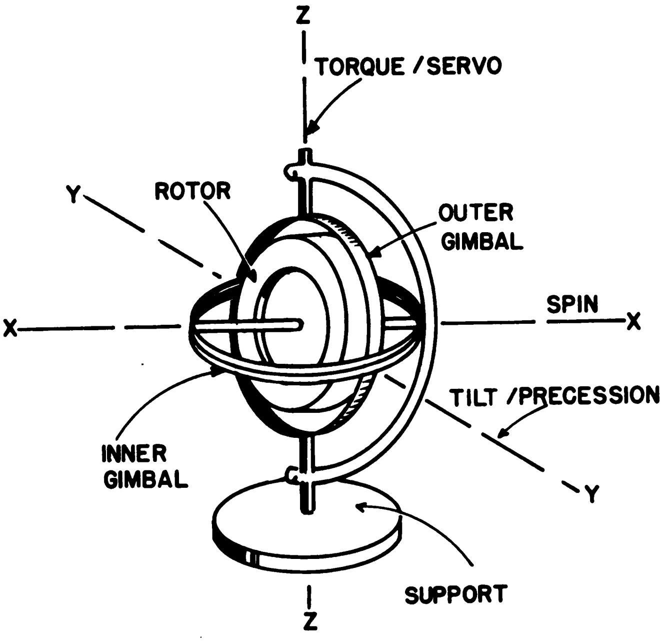


Figure 7–10.—Basic universally mounted gyro.

Should the two gimbals become alined in the same plane, a condition of GIMBAL LOCK would exist. This condition is prevented in practical applications by various means, one of which is by physical stops that restrict the movement of the gyro.

Properties of Gyros

Two fundamental properties of gyros are RIGIDITY and PRECESSION. Rigidity (gyroscopic inertia) is that property of a gyro that causes it to tend to remain fixed in space unless acted upon by some external force. Upon this principle the operation of the stabilizing gyro is based. Precession is that change in the gyro's position resulting from a force having been applied to the spin axis of the gyro. The direction of this change in position may be determined by the LAW OF PRECESSION, which states that a gyro will precess 90 degrees away and in the direction of rotation of the rotor from the force applied. This property of gyros provides the basis on which the principle of rate gyros is based.

Gyro Orientation with the Aircraft

When fire control equipment is mounted in an aircraft, the gyroscopic elements will be orientated with the various axes of the aircraft. The manner in which this is done will depend, to a certain extent, on the equipment and the functions the gyros are expected to perform. Figure 7–11 illustrates the three axes of an aircraft and their relationship to the gyro spin axis. With the gyro mounted as shown, the amount of pitch and/or roll of the aircraft could easily be measured, as the gyro would maintain a stable reference as the aircraft maneuvered.

Gyros may be orientated with any of the aircraft's axes and may also be used in combinations of two or more for determining rates and amounts of movement about any or all of the aircraft's axes. Therefore, to fully understand some of the fire control equipment, it is necessary to understand the orientation of the gyro elements in the equipments and their relationship to the axes of the aircraft.

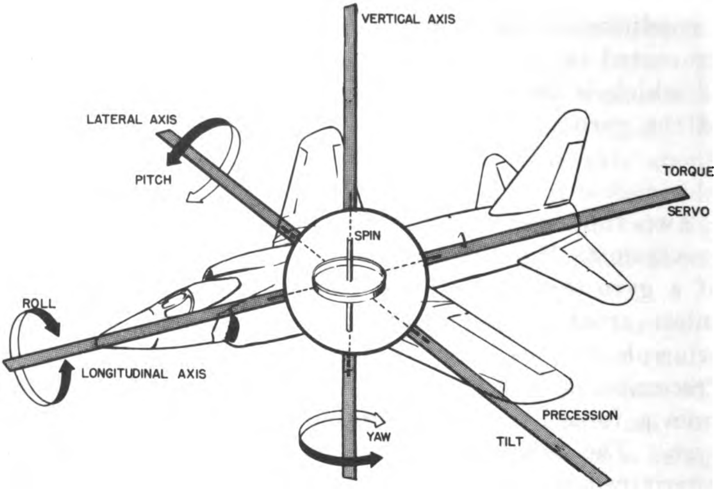


Figure 7–11.—Relationship of gyro axes to the aircraft axes.

Pickoff Devices

To utilize a gyro as a detecting device for solving aircraft fire control problems, it is very necessary to adapt it with some type of pickoff device. This is necessary so that the desired information can be determined and transmitted to the desired unit. Some of the devices used for this purpose are E-TRANSFORMERS, POTENTIOMETERS, and SYNCHROS. These devices were discussed in detail in chapter 5 of this course under the section entitled "Error Detectors."

RATE GYROS

A rate gyro may be defined as a device for detecting the angular rate of change of position of an object. In aviation fire control equipment, we are primarily concerned with the angular rate of change of a target aircraft. However, this rate of change of the target may be determined by measuring the angular rate of change of an antenna locked on the target, or a turret tracking a target.

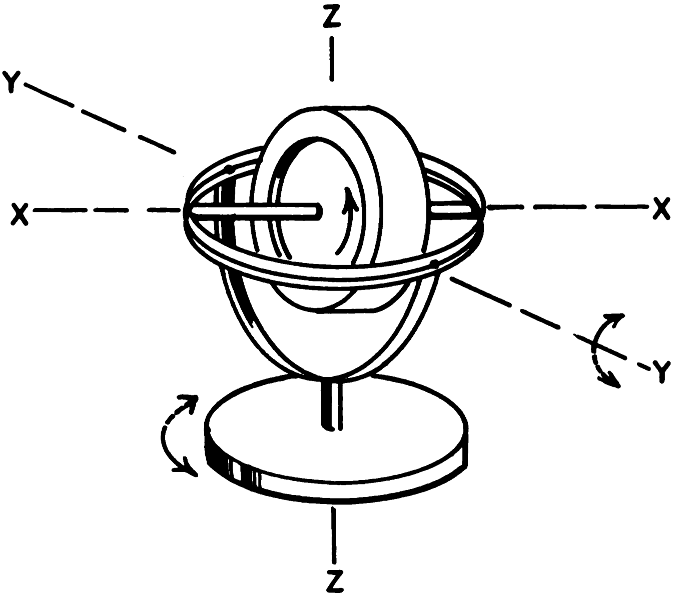


Figure 7–12.—Basic rate gyro.

Target angular rate information may also be determined by measuring the angular rate of change of the attacking aircraft while tracking its target.

Basic Rate Gyro

Basically, a rate gyro is similar to a universally mounted gyro except that it normally has one less gimbal; thus, the freedom of movement of the gyro is limited. Figure 7–12 illustrates the basic construction of a rate gyro showing the limitation on its freedom of movement.

The direction of precession of the gyro about the Y–Y axis will depend upon the direction of the torque applied about the Z–Z axis of the gyro and can be determined by the law of precession. The rate of precession of the gyro will be proportional to the amount of applied torque.

When modified as shown in figure 7–13, the basic rate gyro can produce an output proportional to the rate of turn or rotation of the base about the Z–Z axis. As the

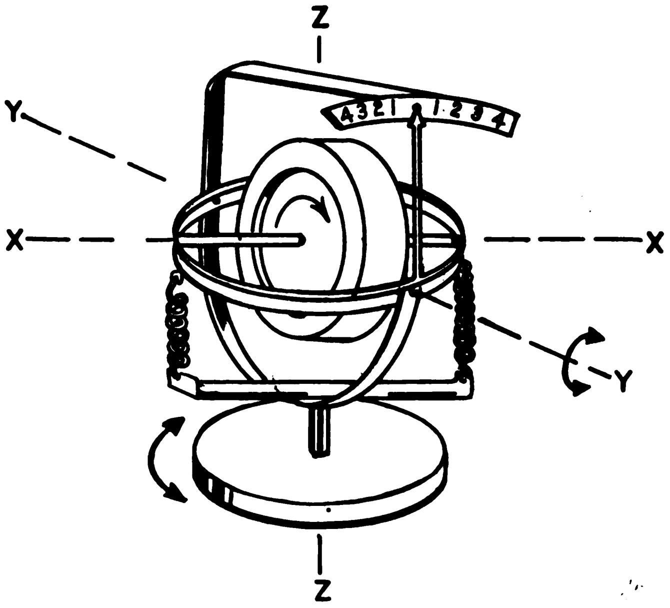


Figure 7–13.—Modified basic rate gyro.

base of the gyro is rotated, precession will begin and continue until one of the calibrated springs overcomes the precessional force. At this time the pointer will remain steady on the scale until there is a change in the rate of rotation of the base. Thus with the assembly properly calibrated, the rate of rotation of the base can be read directly from the scale.

Types of rate gyros.—There are two basic types of rate gyros used in aviation fire control equipment. One type senses a rate of change in one plane while the other type senses a rate of change in two planes simultaneously. The latter type is capable of not only measuring rate of change in two planes, but when supplied with range, ballistic, and other necessary information, is capable of determining the necessary lead angle. A two-plane rate type gyro was discussed in the section entitled "A. F. C. S. Mk 6," of chapter 5 of *Aviation Fire Control Technician 3*, NavPers 10388. For the purpose of this course, these gyros will be referred to as the one-plane and two-plane rate types.

One-Plane Rate Gyro

The one-plane rate gyro is used quite extensively in aviation fire control equipment. This type is generally used in pairs, one for detecting rate of change in elevation and one for detecting rate of change in azimuth. The purpose of this type gyro is to produce an electrical output signal that is proportional to the angular rate of gyro motion about the precession axis. It should be remembered that the rate of motion about the precessional axis is proportional to the force applied about the torque axis.

Theory of operation.—A one-plane rate gyro and its associated circuitry is illustrated in figure 7–14. It consists of a basic rate gyro, a magnetic restraining device used to overcome the precessional force, and a means of generating a voltage indicative of both direction and amount of precession. It should be noted that the magnetic restraining device accomplishes the same function as the calibrated springs used in the basic rate gyro discussed previously.

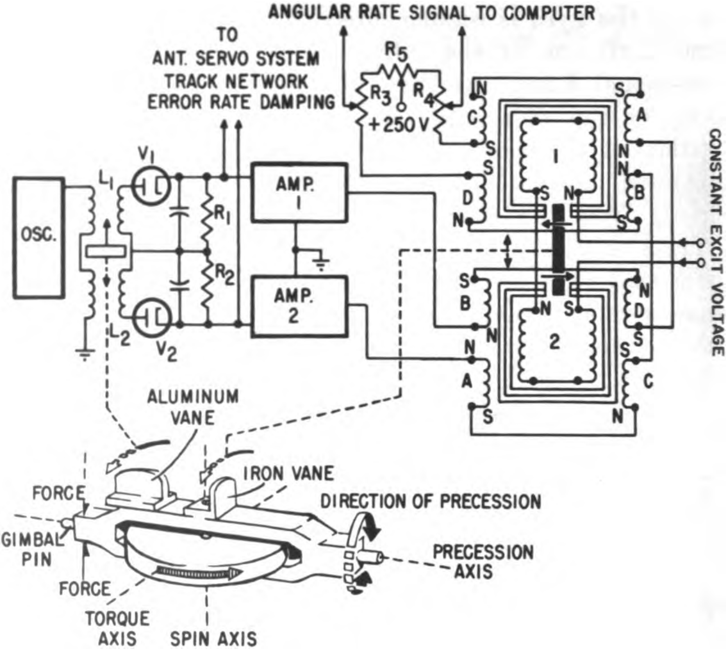


Figure 7–14.—Typical one-plane rate gyro.

The rotor of the gyro consists of a 3-phase induction motor mounted in a single gimbal. Mounted on the gimbal and at right angles to each other are two vanes, one aluminum and the other iron.

The iron vane is used in conjunction with the two horseshoe electromagnets to form the restraining device. The iron vane is positioned in the air gap between the two electromagnets as shown in figure 7–14. It is linked with flux as indicated by the arrows passing from the pole faces through the gaps and through the iron vane. (Note: Withdrawing an iron vane or core from a magnetic field requires sufficient force to overcome the attraction of the magnetic field. The force required is proportional to the strength of the magnet and varies inversely as the square of the distance from the magnetic poles.)

The electromagnets contain two sets of windings as shown on the schematic diagram. One set of windings is excited by a well-regulated constant current. The function performed by the constant current is to calibrate the gyro. The other set of windings is called the variable current or torque windings. The function of these windings is to provide a constant restraining force on the iron vane. When the gyro attempts to precess, the iron vane moves in the gap in the direction of precession. When the iron vane tries to move out of the gap, its movement is restrained by the flux in the gap which attracts the iron vane to the magnet pole pieces. Thus, the total amount of precession about the gimbal axis for a constant precessional force is that angle through which the iron vane must move to develop a restraining force equal to the precessional force. Since the gyro in precessing rotates the gimbal, the aluminum vane also moves through the precession angle.

The aluminum vane is placed between two inductors, L_1 and L_2, as shown in the schematic diagram in figure 7–14. The arrows indicate the movement of the aluminum vane when the gyro precesses. The primary windings of these inductors are connected in series and excited by the output of the RF oscillator.

The output of the oscillator is coupled from the primary to the secondary of the two inductors, L_1 and L_2. When the gyro precesses, the aluminum vane moves from its centered position and takes a position nearer to one inductor and farther from the other inductor. A nonferrous piece of metal placed in close proximity to an inductor effectively short circuits some of its turns and reduces its inductance and its reactance. The number of effectively shorted turns is a function of the distance separating the nonferrous metal and the inductor. If the aluminum vane moves toward inductor L_1 and away from inductor L_2, the reactance of L_1 is reduced and reactance of L_2 is increased, resulting in a decreased voltage across the secondary winding of L_1 and an increased voltage across the secondary winding of L_2.

When the aluminum vane is centered between the inductors, the voltage applied to the plates of the diodes are equal and the diodes draw equal currents. However, when the gyro precesses as discussed in the previous paragraph, a greater voltage is applied to the plate of V_2 and a lesser voltage is applied to the plate of V_1. The detector with the greater plate voltage conducts more, and the difference between the currents drawn by the diodes is proportional to the angular rate of the gyro. The output voltage, which is the algebraic sum of the voltages across R_1 and R_2, is fed to the amplifier for amplification.

As shown in figure 7–14, the conduction currents of amplifier 1 and amplifier 2 are drawn through series-connected windings on each electromagnet. For zero angular rate, amplifiers 1 and 2 conduct equally and the resultant flux set up as a result of these conduction circuits in each core is zero. Hence, the series-connected windings, shown inside the magnetic cores, establish equal fluxes with the polarities as shown across the gaps. With the iron vane in its zero angular rate position, equal forces exist which cancel each other. Any movement of the iron vane changes the reluctance of the electromagnetic core gaps. Hence, the change in flux linkage to the iron vane unbalances the mutual attracting forces applied to the vane. In order to obtain a linear calibration of the angular movement of the iron vane versus degrees per second of angular rate, the flux in the gap into which the iron vane moves must decrease and the flux in the gap out of which the vane moves must increase. These flux changes must be so proportioned that for every degree per second of angular rate change, the iron vane moves through the same proportional angle to reach a position at which the attracting forces from the gaps cancel each other. This requirement is met by the arrangement of the windings through which the variable current flows.

Using the conditions established by the example previously stated, we shall determine if the operation of the variable current windings fulfill the established requirements. However, let us first note the polarity of the magnetic fields established by each variable current winding. On magnet 2, the fields established by windings A and C aid the field resulting from the constant current winding, while the fields established by windings B and D oppose that of the constant current windings. Magnet 1 has a similar arrangement as shown in figure 7–14.

The increased current of amplifier 2 resulting from the upward movement of the vanes causes an increase in the resulting magnetic field strength of magnet 2 and a corresponding decrease in the field strength of magnet 1. Thus, there is an increase in the flux of the electromagnet from which the iron vane moves while the flux in the other electromagnet is decreased a proportional amount.

The output of the rate gyro is a voltage based on the difference in current of the two amplifiers through their respective variable current windings. Potentiometer R_5 is used to balance the current flow through the amplifiers and their variable current windings with a zero angular rate input. Potentiometers R_3 and R_4, which are ganged together, provide a means of determining the output voltage for a given angular rate input to the gyro.

Two-Plane Rate Gyros

The function of the two-plane rate gyro is to generate the correct lead angle and transmit signals proportional to the azimuth and elevation components of the lead, for use in positioning the steering references on a radar indicator of an all-weather system.

The mounting of the gyro and gimbal arrangement is similar to that of a free gyro in that the gyro frame and housing may be moved, within limits, about all three axes of the gyro. The eddy-current constrained gyro principle of operation applicable to this gyro was discussed in the section entitled "Aircraft Fire Control System Mk 6," in chapter 5 of *Aviation Fire Control Technician 3*, NavPers 10388.

Theory of operation.—The gyro motor housing, from which the gyroscopic action is obtained, is mounted in gimbals between two spinning aluminum disks. The gyro rotor and each of the spinning disks are individually driven by induction motors. The mounting of the assembly is such that when the frame or gyro case and the gyro motor housing are alined with each other, the spin axes of the gyro and the spinning disks coincide.

Mounted on opposite ends of the gyro motor housing are the elevation and azimuth coils. Each set of coils is composed of two magnetic cores and two windings. As illustrated in figure 7–15, half of each winding is wound on one core and the remaining half is wound on the other core and in the opposite direction.

Three range coils are mounted around the gyro frame and between the spinning disks as shown in figure 7–16. They are connected in series in such a manner that the magnetic flux set up by each travels in the same general

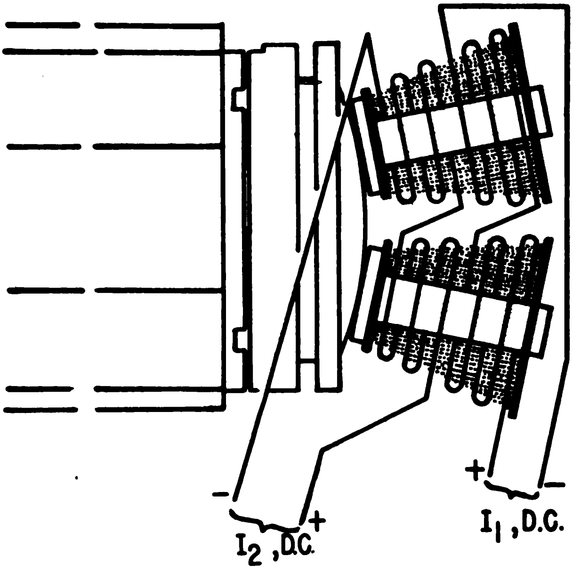


Figure 7–15.—Elevation or azimuth coil winding schematic.

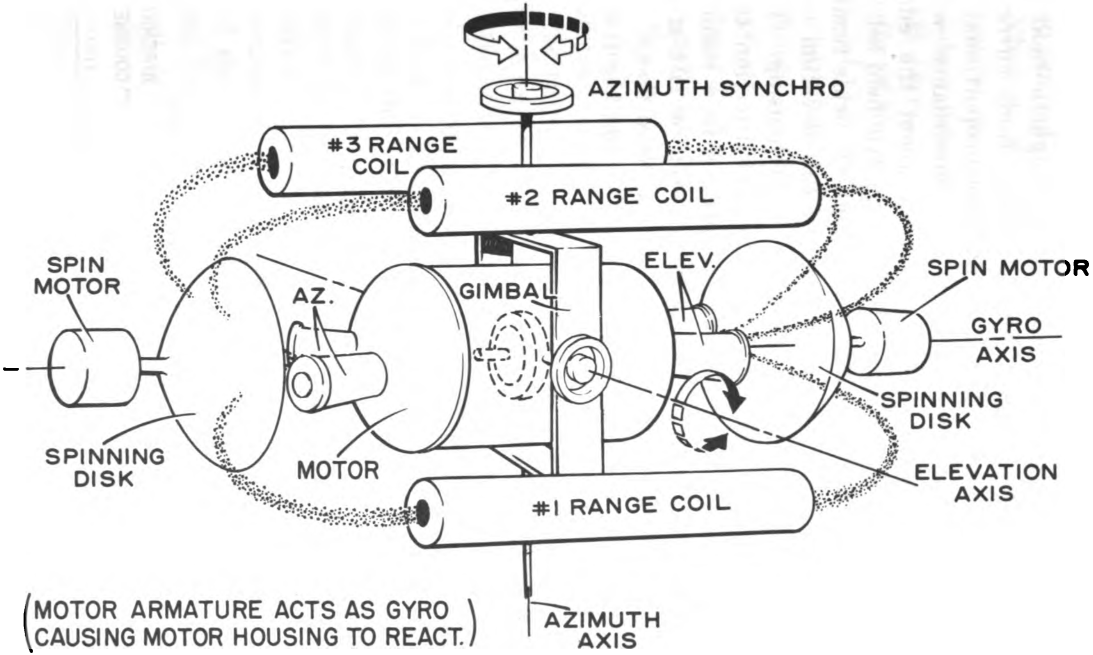


Figure 7–16.—Two-plane rate gyro schematic.

direction. The range coils are energized by a current whose amplitude varies inversely with range as obtained from the radar.

The spinning disks are rotating in the magnetic field set up by the current through the range coils. Eddy currents are induced in the spinning disks and are proportional to the currents flowing in the coils. In accordance with Lentz's law, a magnetic field is set up about the eddy currents which is in opposition to the magnetic field set up by the coils. The interaction of the magnetic fields results in a force being applied to the cores of the elevation and azimuth coils, and hence to the gyro motor housing. The resultant force is of such a magnitude and direction that it causes the gyro motor housing to precess in a manner which TENDS TO ALINE THE EFFECTIVE CENTER OF THE MAGNETIC FIELD WITH THE CENTER OF THE SPINNING DISKS. If the coils are energized in such a manner so that the forces

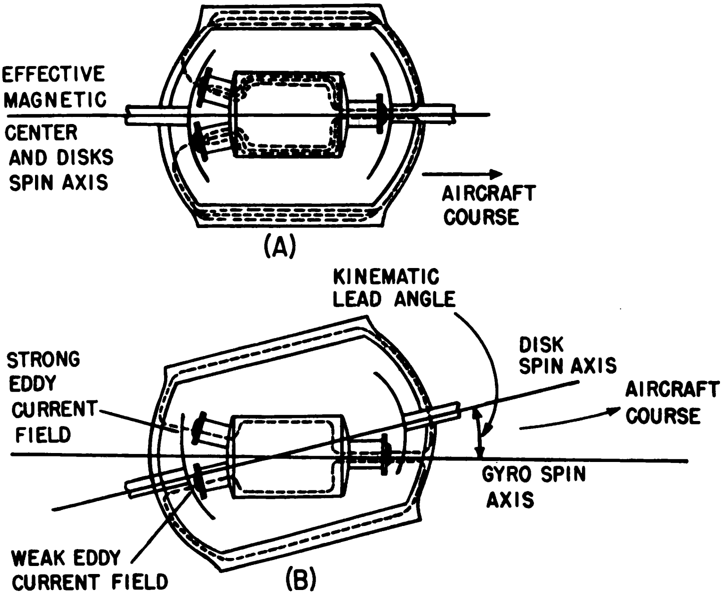


Figure 7–17.—Relation of spinning disks and magnetic field.

acting on each core are equal, they will cancel each other out, and thus the gyro motor housing will not precess. (See fig. 7–17 (A).)

When an aircraft in which a gyro is mounted begins to maneuver as in tracking a target, the gyro will tend to maintain its spin axis in the original position. As the aircraft turns, the spin axis of the gyro and the effective center of the magnetic field are offset in respect to the spin axis of the disks. Therefore, the magnetic fields produced by the induced eddy currents in the spinning disk are unbalanced, as shown in figure 7–17 (B) and the resultant force acting on the gyro causes it to precess.

As the pilot continues to turn while tracking the target, the gyro continues to precess. The angular displacement of the gyro spin axis and the spin axis of the disks will increase until the resultant force of the magnetic field is sufficient to impart a rate of precession to the gyro equal to the turning rate of the aircraft. When the turning rate of the aircraft and the gyro have become equal, the angle between the spin axis of the gyro and axis of the spinning disks is equal to the KINEMATIC LEAD ANGLE required to hit the target. (See fig. 7–17 (B).)

With the lead angle generated, signals indicative of the elevation and azimuth components of the lead are transmitted by means of synchro transmitters for use in positioning the steering reference on the radar indicator. The elevation synchro transmitter is mounted on the gyro gimbal and the azimuth synchro transmitter is mounted on the gyro frame as shown in figure 7–16. Thus, any displacement of the gyro spin axis from the axis of the spinning disks will be vectored into its azimuth and elevation components and transmitted as required.

The azimuth and elevation coils are used to modify the kinematic lead angle for such factors as gravity drop, angle of attack, launcher angle, and angle of skid. Essentially, the coils shift the effective center of the magnetic field set up by the range coils incorporating the necessary corrections in the lead angle.

Any variation in elevation or azimuth coil current does not vary the overall strength of the magnetic field. This is illustrated in figure 7–15. If I_1 and I_2 are equal, the magnetic fields set up by each are equal and opposite to each other, resulting in cancellation. If I_1 increases and I_2 decreases, or vice versa, the pole strength of one core will increase and the other will decrease. This results in a shifting of the center of the overall magnetic field.

STABILIZING GYROS

A basic free gyro may be used as a stabilizing gyro by modifying the mounting and placing certain limitations on its movement. Unlike the rate gyro discussed previously, the stabilizing gyro is used to establish a fixed reference from which it is possible to measure amounts of movement or displacement. Stabilizing gyros may be used to establish either horizontal or vertical references, and may be used in groups of two or more to establish planes of reference. A typical application of a stabilizing gyro may be found in an Armament Control System where it is used to stabilize the radar antenna and measure the amount of roll of the aircraft for use in missile guidance.

In addition to the basic components of a free gyro, a stabilizing gyro has provisions for detecting any deviation from the stabilized reference and transmitting this information to the equipment as required. It normally has some means of erection or alining its spin axis with a predetermined reference. A stabilizing gyro may also include a means of caging; that is, restricting or locking its gimbals.

Single Unit System

The gyro to be discussed in this section is often referred to as a vertical gyro and is typical of those used in aviation fire control equipment. As the name implies, this gyro provides a vertical reference from which amounts of pitch and roll can be measured. This information may be used to stabilize the radar antenna and to position an artificial horizon on the radar indicator.

Components.—The complete gyro assembly consists of two major components enclosed in a case; namely, a vertical gyro and a vertical reference device. The heart of the gyro is the rotor of a synchronous motor, the case of which is mounted in two gimbals. A synchro transmitter and a reversible torque motor (sometimes referred to as a torquer) are mounted on opposite ends of both the roll and pitch axis. The torque motors are used to apply torque or precessional force about either gimbal to cause the gyro to precess to the vertical position. They are of the split winding reversible induction type which permits torque to be applied in either direction.

The vertical reference device is a sealed case mounted on the bottom of the inner gimbal and is used to provide the gyro information necessary to establish a vertical reference.

Theory of operation.—With the gyro operating and erected as shown in figure 7–18, any movement of the aircraft about the pitch or roll axes will be detected. A signal proportional to the amount of pitch and/or roll will be transmitted by the respective synchro transmitter for use as required by the equipment concerned. The function of the gyro is to maintain a vertical reference over an extended period of time. However, the gyro is not capable of accomplishing this due to drift caused by friction of its bearings and sliprings, or apparent drift caused by the rotation of the earth. To counteract this possibility, a vertical reference device is used to cause the gyro to erect itself toward gravity when the aircraft is flying straight and level.

The vertical reference device is composed of a pendulum, suspended from the inner gyro gimbal, and four metal disks. The disks are electrodes positioned at 90 degrees to each other. The pendulum and disks are suspended in an electrolytic solution and sealed in a case. The case is rigidly attached to the inner gimbal and positioned so that the pendulum hangs in the exact center of the four electrodes when the aircraft is in straight and level flight. The pendulum is at ground potential while each pair of

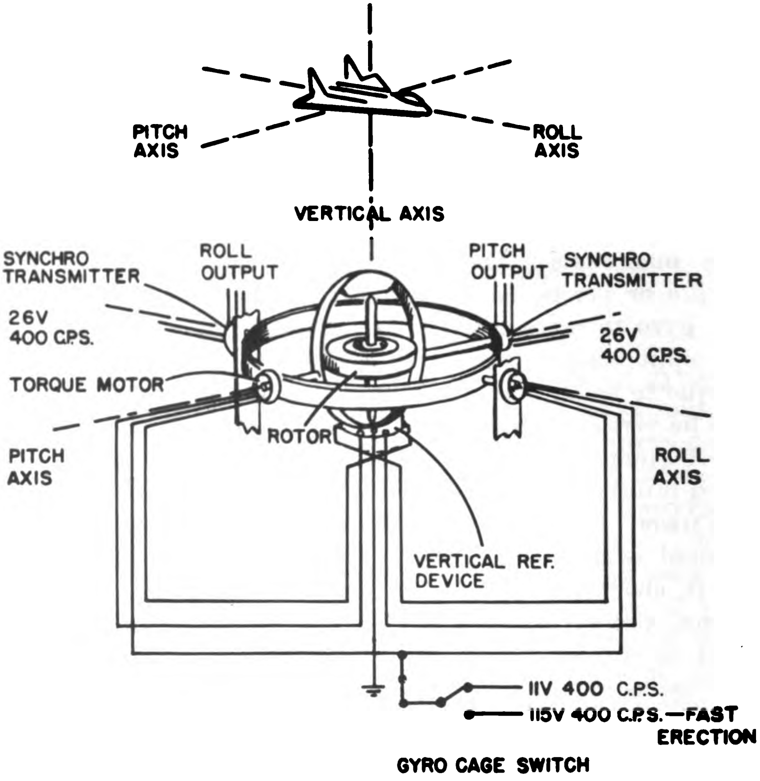


Figure 7–18.—Vertical gyro functional diagram.

electrodes is connected across the control winding of a positioning motor. (See fig. 7–19.)

In order to describe the action, assume that the gyro has erected so that its spin axis is pointing toward the center of the earth and the pendulum is in the exact center of the vertical reference device. This causes the resistance path through the electrolyte from each of the four electrodes to the pendulum to be exactly equal. The 400-cycle voltage applied to the center tap of each of the torque motor control windings causes current flow in opposite directions through each half of the control windings. Since the two halves

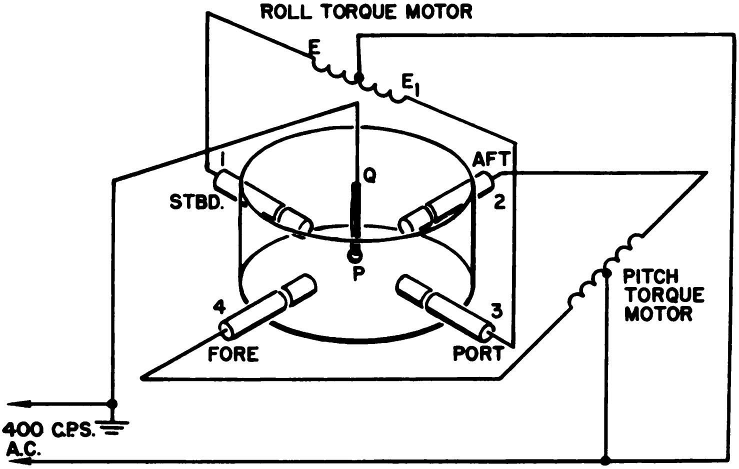


Figure 7–19.—Vertical reference device functional diagram.

of the control winding are identical, the currents in each half are equal. The equal currents cause equal magnetic fields in each half of the control winding but, since the two currents flow in opposite directions, the fields oppose each other. Thus, no torque is developed in the control windings and the torque motor remains fixed.

Now assume that the gyro is positioned so that the pendulum is closer to electrode 1 than 3 but is still an equal distance from electrodes 2 and 4. This causes the resistance path from electrode 1 to the pendulum to decrease and that from electrode 3 to increase, causing a respective increase and decrease in current. Since the larger magnetic field is developed across the half winding connected to electrode 1, it reacts with the field developed across the reference winding, causing a torque which turns the roll torque motor rotor. Thus, the direction of rotation causes the pendulum to center between the four electrodes.

When the aircraft enters a maneuver which diverts it from straight and level flight, a force is exerted on the pendulum which is not true gravity. This force would cause the pendulum to move to one side of the vertical reference device. The erection system would erect the gyro to this new false reference, thereby returning the pendulum to the center of the vertical reference device. If this happened, the gyro would be erected to any lateral acceleration which is applied to the aircraft.

Since it is desirable for the gyro to remain in the same position to which it was originally erected, the energizing potential is removed from the reference windings of the torque motors when the aircraft enters a maneuver. This allows the gyro rotor to remain fixed to its original reference. However, if the maneuver is sustained for any appreciable amount of time, the gyro will drift from its original position due to the force transmitted through the friction present in the bearings of the gyro gimbals. When the aircraft is back in level flight, the reference winding is again energized and the gyro is once more erected to the earth's gravity.

Should the gyro have drifted a great amount or possibly tumbled due to extended maneuvers, the pilot may cause the gyro to erect more rapidly than normal by pressing the fast erection switch. This switch applies a higher voltage to the reference windings of the torque motors, increasing their torque and thereby reducing the time required to reposition the gyro.

Multiple Unit System

The basic multiple unit system to be discussed is typical of the stabilizing systems presently used in aviation fire control. This system is used to establish a horizontal reference platform and a magnetic north reference for use in horizontal high altitude bombing. The stabilizing system isolates the optical and radar lines of sight from airplane rotations.

The gyro stabilizing system comprises only a portion of the complete stabilizing system. Figure 7–20 illustrates the relationship of the gyro stabilizing system to the complete stabilizing system. The accuracy of the system depends, in a large part, upon a number of inputs as shown in figure 7–20.

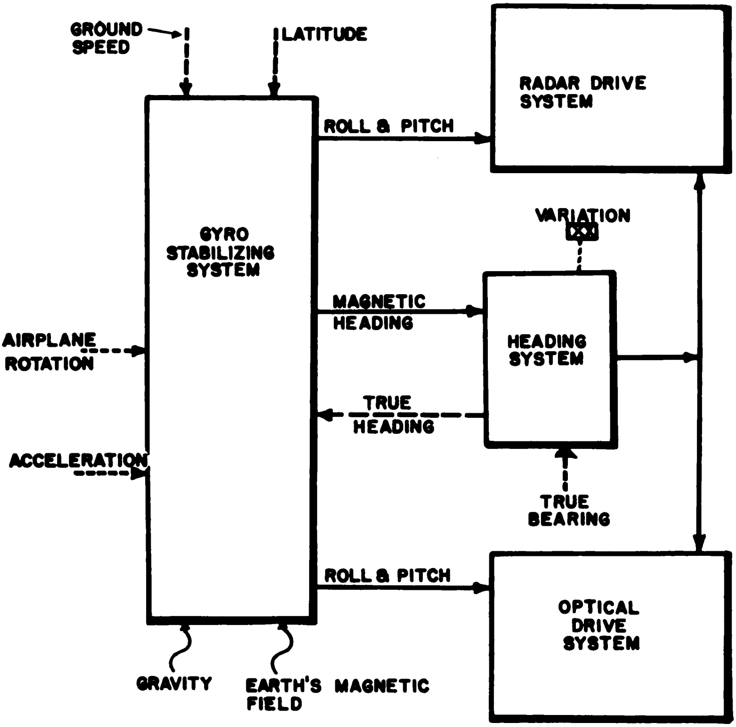


Figure 7–20.—Stabilizing system block diagram.

For purpose of explanation, the gyro stabilizing system may be divided into ROLL AND PITCH SYSTEMS and a HEADING SYSTEM.

ROLL AND PITCH SYSTEMS.—The function of the roll and pitch systems is to establish the horizontal plane or platform, measure amounts of aircraft roll and pitch in respect to that plane, and transmit this information to other components of the stabilizing system. It should be remembered that the amount of roll and pitch establishes the position of the aircraft in respect to the horizontal plane. The roll system and pitch system each contain the same major components which are as follows:

1. Gyro.

2. Erection system.
3. Servo loop.
4. Earth's rotation correction circuit. (Referred to as ERC.)

The pitch and roll systems must function together to establish the horizontal platform. The pitch and roll gyros are mounted with their spin axis vertical in a single gimbal called the pitch gimbal.

The axis of rotation of the pitch gimbal is in the horizontal plane and perpendicular to the longitudinal axis of the aircraft. The pitch gimbal is, in turn, mounted in another gimbal called the roll gimbal. The axis of rotation of the roll gimbal is also in the horizontal plane but parallel to the longitudinal axis of the aircraft. The gyros are mounted with their tilt axis at right angles to each

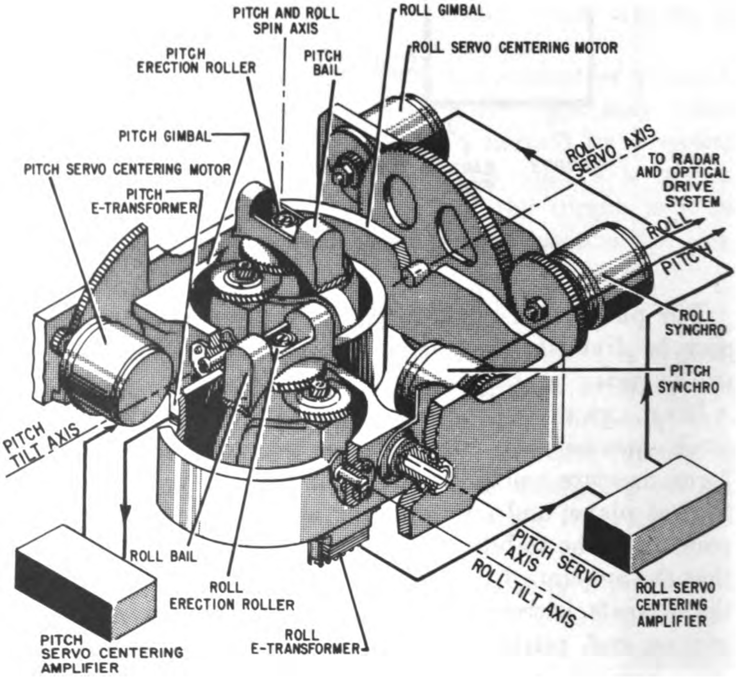


Figure 7–21.—Roll and pitch gyro mounting.

other. Thus, two universally mounted gyros establish a stable horizontal platform as shown in figure 7–21.

The GYROS are both induction type motors, identical in construction. The rotor rotates about the stator for maximum inertia due to its limited size. A circular magnet is mounted on top of the rotor. As the rotor spins, its motion is magnetically coupled to a drag cup mounted just above it, also causing it to spin. The drag cup is mounted in bearings on the stationary shaft. It rotates with the gyro rotor at a low speed and torque, and drives a bell gear through a gear train as shown in figure 7–22. The bell gear has a cork faced roller attached to its upper side and centered on the stationary shaft. The cork faced roller is used to supply torque for the erection system.

The ERECTION SYSTEM consists of the bails and their associated circuitry. The bails are inverted pendulums which

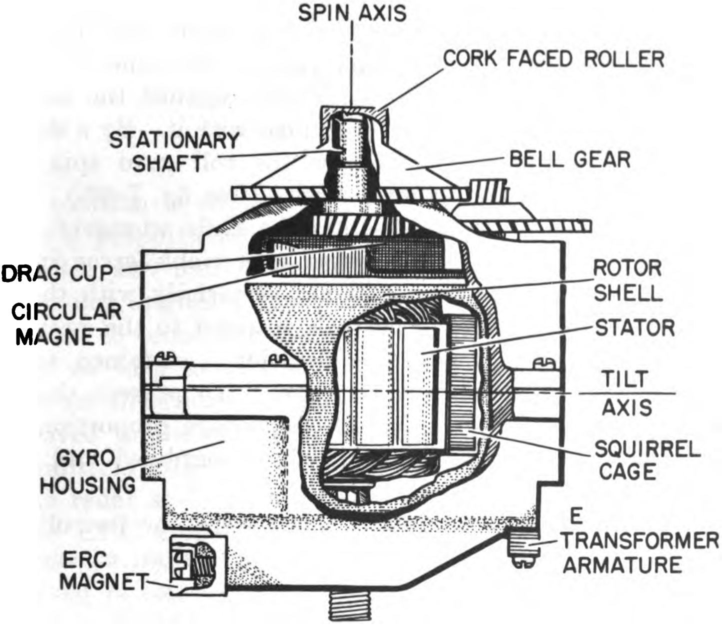


Figure 7–22.—Vertical gyro cross sectional diagram.

sense the direction of gravity and maintain the spin axes of the vertical gyros in this direction. Roll and pitch bails are identical except for their orientation on the pitch gimbal. The pitch bail is mounted in bearings on the pitch gimbal at right angles to the pitch tilt axis, and is arched athwartship over the pitch gyro. The roll bail is similarly mounted at right angles to the roll tilt axis. The bails are slotted lengthwise to receive the cork rollers.

If the pitch gimbal is level, the bails vibrate slightly and thus bear equally on both sides of the rollers with no net torque applied to the gyros. If the pitch gimbal tilts about the pitch servo axis, one side of the slot in the pitch bail bears against the roller more often than the other side. This results in a small net force between one side of the bail and cork roller. This force and the relative motion between the rotating cork face and the bail cause a friction force which acts along a tangent to the roller at the point of contact. Because the friction force imparted to the gyro about the tilt axis opposes the roller's rubbing, and since the roller and gyro rotor turn in the same direction, the friction torque precesses the gyro against the bail toward the vertical carrying the gimbal with it. By a similar process, the roll bail maintains the roll gyro spin axis vertical and the roll gimbal level. (See fig. 7–23.)

The bail lock circuit disables the bails whenever horizontal accelerations might cause appreciable error in the gyro. Any acceleration combines vectorially with the acceleration of gravity. The bails respond to the resultant vector and, if the spurious acceleration is sustained, set up a false stable reference in the gyro. To prevent this, an accelerometer is used to produce a voltage proportional to any horizontal acceleration which is amplified and used to energize the bail locks.

Two SERVO LOOPS are used in this system, one for roll and one for pitch. They are similar in operation; each counteracts disturbing torques from the servo axis of its gyro.

When any disturbing torque is applied about the gyro servo axis, the gyro begins to precess about the tilt axis.

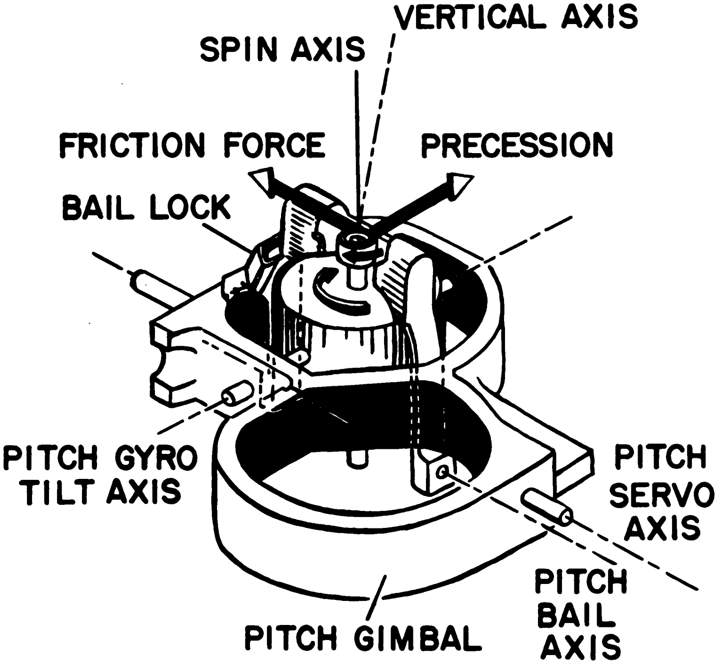


Figure 7–23.—Bail operation.

This rotation is sensed by the E-transformer, which generates a proportional alternating voltage. This voltage is amplified and used to control the servo centering motor. The motor applies a countertorque to the gyro servo axis sufficient to cancel the disturbing torque. This action continues as long as the disturbing torque persists. Servo loops are illustrated in figure 7–21.

Geared to the roll and pitch gimbals are two synchro transmitters which transmit roll and pitch information to the radar and optical drive systems.

The ERC CIRCUITS correct the gyro's vertical position for errors due to the earth's rotation, which is further modified by the aircraft's speed and latitude. The correction is computed outside the gyro stabilizing system, and a signal indicative of the ERC is transmitted by the ERC circuit to the appropriate roll or pitch ERC coils located on the pitch gimbal.

Each coil applies a torque to its respective gyro, causing tilt and a resulting displacement of the roll or pitch gimbal. On the side of each gyro case, a U-shaped permanent magnet is mounted, with its poles facing out. (See fig. 7–22.) The ERC coil is mounted on the gimbal opposite this magnet.

In the no tilt position, the pole piece of the coil is located midway between the poles of the permanent magnet, with no current flowing in the coil. The coil pole piece is a north or south pole, depending on the direction of current energizing its winding. It attracts one or the other of the permanent magnet poles, applying a torque about the tilt axis which displaces the gimbal at a rate proportional to the ERC signal. Hence, the gimbal is displaced at a rate equal to the displacement rate of the vertical.

THE HEADING SYSTEM.—This system establishes magnetic north direction in the equipment, measures airplane magnetic heading with respect to this direction, and transmits it to a computer unit as required by the associated equipment.

The system is composed of the following major components:

1. Azimuth gyro.
2. Servo loop.
3. Compass circuit.
4. ERC circuit and manual control.

The AZIMUTH GYRO is similar to the roll and pitch gyros in that it is an induction type motor without the circular magnet and its associated components. It is mounted in the azimuth gimbal with its spin axis normally horizontal as shown in figure 7–24. The gimbal arrangement makes it a universally mounted gyro allowing 360 degrees rotation of the gyro about its servo axis.

The pitch gimbal and the azimuth-pitch gimbal are linked together by a gear train and are driven by the same

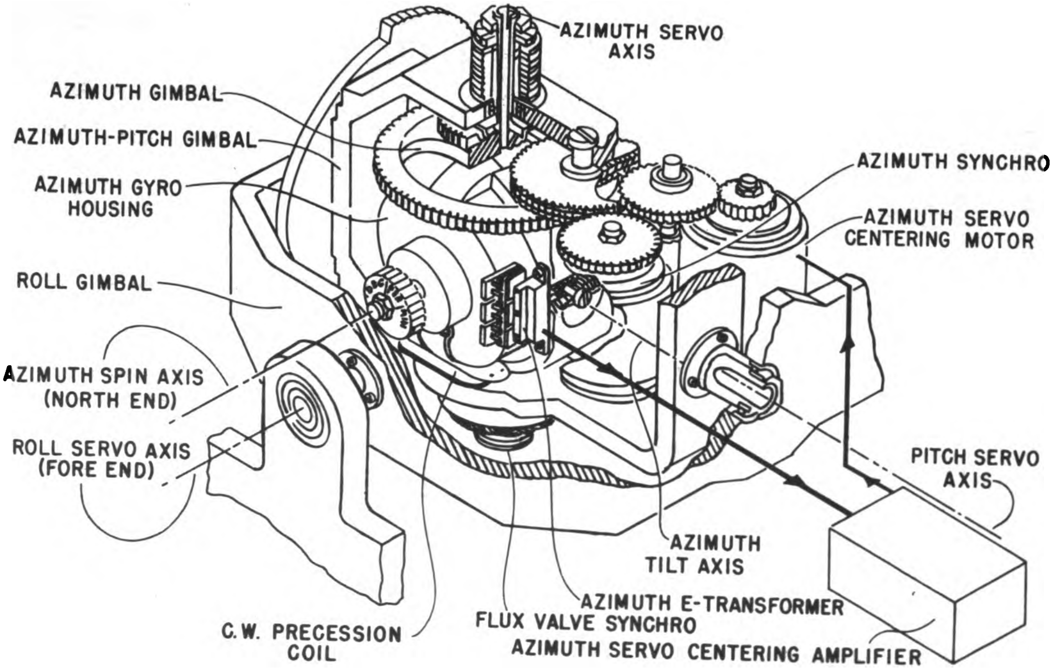


Figure 7–24.—Heading gyro and servo loop.

pitch servo centering motor. The azimuth gimbal and gyro are driven through a gear train powered by the azimuth servo centering motor. Any displacement of either the azimuth gyro or azimuth gimbal is coupled to the azimuth synchro by a gear train.

The SERVO LOOP functions in the same manner as the servo loops in the roll and pitch systems. The components are identical in construction and operation and are also shown in figure 7–24.

Any tilt of the azimuth gyro from the horizontal plane will result in a torque being applied about the servo axis by the servo loop causing the gyro to precess back into the horizontal plane. This correction, as well as any movement of the aircraft about its vertical axis, is transmitted to the optical and radar line of sight by the azimuth synchro.

The COMPASS CIRCUIT utilizes the earth's magnetic field to aline the azimuth gyro's spin axis with magnetic north. The flux valves detect the earth's magnetic field and set up a field in the stator of the flux valve synchro in a north-south direction. The stator of the flux valve synchro is secured to the base of the azimuth-pitch gimbal and thus turns with the motion of the aircraft in azimuth along with the flux valves. The rotor of the flux valve synchro is attached to the lower shaft of the azimuth gimbal and is therefore positioned by the azimuth gyro.

The voltage induced into the rotor of the synchro will represent the angle between the spin axis of the gyro and the magnetic north regardless of the heading of the aircraft. Also, if the gyro should precess out of the north-south position, an error voltage would automatically be induced into the rotor of the flux valve synchro.

This error voltage is transmitted to the compass tie-in amplifier, the output of which is two pulsating direct currents with relative amplitudes corresponding to the error voltage. These currents are coupled to their respective precession coils on the azimuth gimbal; one on either side. The net torque developed between the precession coils and their armatures cause the gyro to precess in a direction so as to null out the flux valve synchro. The spin axis of the gyro is then in a north-south direction.

The ERC AND MANUAL control circuits are used to control current through the precession coils when operating conditions warrant. Compass control of the precession coils may be interrupted when any of the following conditions exist:

1. Acceleration is detected by either the roll or pitch accelerometer.
2. Associated equipment requires ERC operation.
3. The azimuth gyro control switch is placed in manual position.

The ERC is computed outside the gyro assembly by its associated equipment. In all cases the ERC circuit takes over immediately and performs the same function as discussed previously in the roll and pitch system. Current proportional to the earth's rotation are applied to the precession coils and the net torque precesses the gyro the required amount and direction.

When the azimuth gyro control switch is placed in manual position, the ERC circuit remains in control until an additional switch called the precession switch is actuated.

GYROSCOPE MAINTENANCE

The maintenance of gyro systems such as those discussed in this chapter consists mainly of cleaning, performing checks, and analyzing results. Gyro units whose performance do not fall within the limits specified by the *Handbook of Service Instructions* for the equipment concerned will normally be removed from the aircraft and forwarded to the appropriate overhaul facility.

Lubrication of gyro assemblies is not recommended under field conditions. It should normally be done only after proper cleaning of the unit which requires special precautions. When cleaning gyro units, all applicable precautions discussed in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388, should be observed. An additional precaution to be observed is that of NO SMOKING. Tobacco ashes can cause faulty functioning of bearings and other components. The *Handbook of Service Instructions* for the equipment should be consulted for special precautions, procedures, cleaning solvent, and lubricants to be used. All cork surfaces, bearings, sliprings, and electrical contacts will require special attention in cleaning.

In many cases, special test equipment will be required for making performance check and alining the equipment. Special instructions are normally available for each type of special test equipment and should be followed when using the equipment.

RELATIVE WIND TRANSDUCERS

A relative wind transducer is a precise self-powered device used to sense the wind direction relative to a reference axis of an aircraft. It may also be called an airstream direction detector, wind direction transmitter, or angle of attack and angle of skid transmitter. However, the device will be referred to as a relative wind transducer throughout this course.

Application

The relative wind transducer is used quite extensively throughout the field of aviation. However, only their application to the fire control problem will be discussed in detail in this chapter.

In the solution of the fire control problem, information on relative wind about the aircraft's axes must be supplied the computer. Relative wind direction can be obtained by determining the ANGLE OF ATTACK and ANGLE OF SKID. Effectively, these measurements are an indication of the movement of the aircraft through the air mass in respect to the aircraft's axes.

However, it should be noted that the transducers detect the local direction of airflow at the mounting location of the transducers. This information must be corrected for position errors associated with their location. The correction factors necessary are primarily a function of Mach number; i.e. the relationship existing between the instantaneous aircraft velocity and the speed of sound in air at flight conditions. The local direction of airflow information is corrected for Mach number by an angle of attack and skid computing system before being transmitted to a fire control computer.

Typical Relative Wind Transducers

There are two types of relative wind transducers used by the Navy in conjunction with aviation fire control equipment. They are the probe type and vane type. The output of either type provides the same information but they differ in their construction.

PROBE TYPE.—The probe type relative wind transducer may be used to determine the angle of attack or angle of skid of an aircraft.

The ANGLE OF ATTACK transmitter or transducer consists of a probe and associate assembly, mounted on the side of the aircraft fuselage so that the probe reference axis is parallel to the boresight or armament datum line. The sensing element of the transmitter is a hollow cylindrical probe, approximately 4¼ inches long and ⅝ inch in diameter. (See fig. 7–25.) The probe, which is free to rotate through 50 degrees about the axis, is divided longitudinally by a metal separator. Two symmetrical longitudinal slots, approximately two inches long are cut into the probe at an equal distance each side of the separator. The separator permits the pressure impinging on either slot to be impressed through the corresponding orifice in the enclosed case at the bottom of the probe to the impeller within the case. The probe is mechanically linked to the impeller or paddle. The paddle, which is a precision fitted element, is sensitive to any differential pressure at the orifices, and rotates in a direction so as to equalize the difference—that is, to reduce the differential pressure to zero. At this time the pressure on both sides of the paddle is equalized. In so doing, the paddle, by means of the linkage, rotates the probe to realine the slots to the null position relative to the direction of the local airstream.

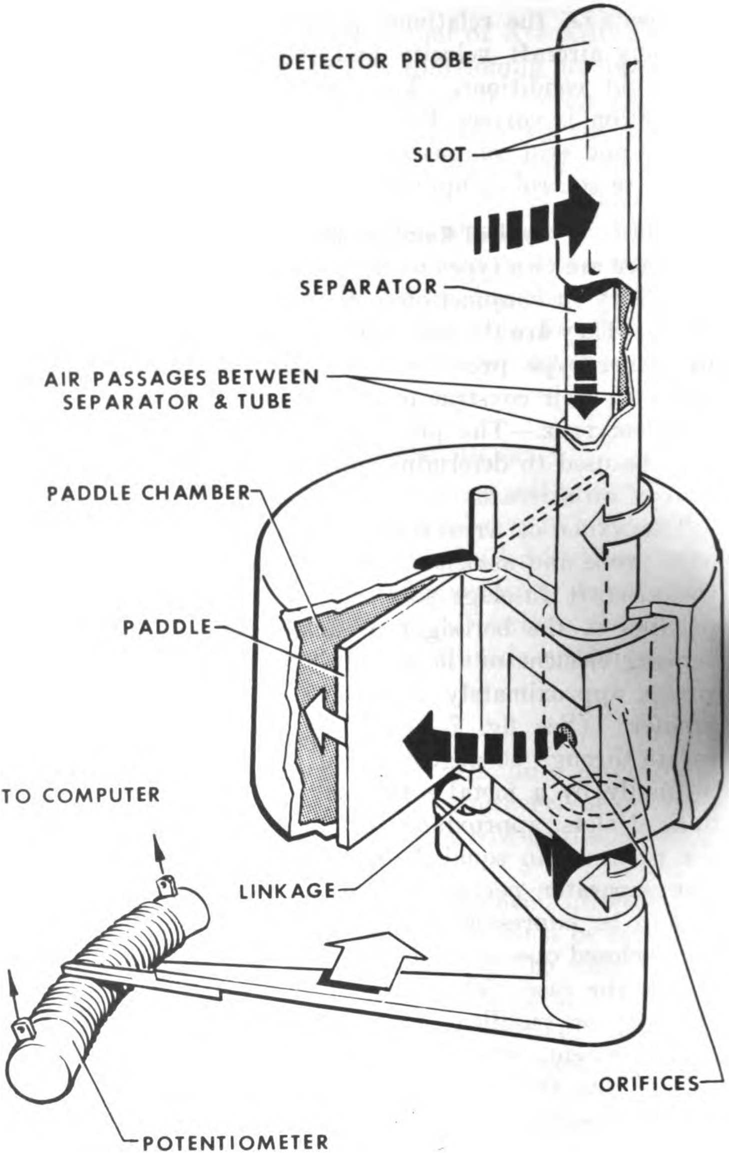


Figure 7–25.—Probe type relative wind transducer.

The base of the probe is also mechanically linked to the contact arms of two identical precision potentiometers attached to the bottom of the case. The instantaneous angular position of the probe is translated by means of the potentiometers into electrical signals which represents the local angle of attack of the aircraft. The output of the transmitter is fed to various equipments in the aircraft, one of which is a fire control computer.

The ANGLE OF SKID transmitter or transducer is similar to the angle of attack transmitter, except that its base houses one potentiometer rather than two. The transmitter is mounted in an approximately vertical position underneath the fuselage so that the boresight position of the

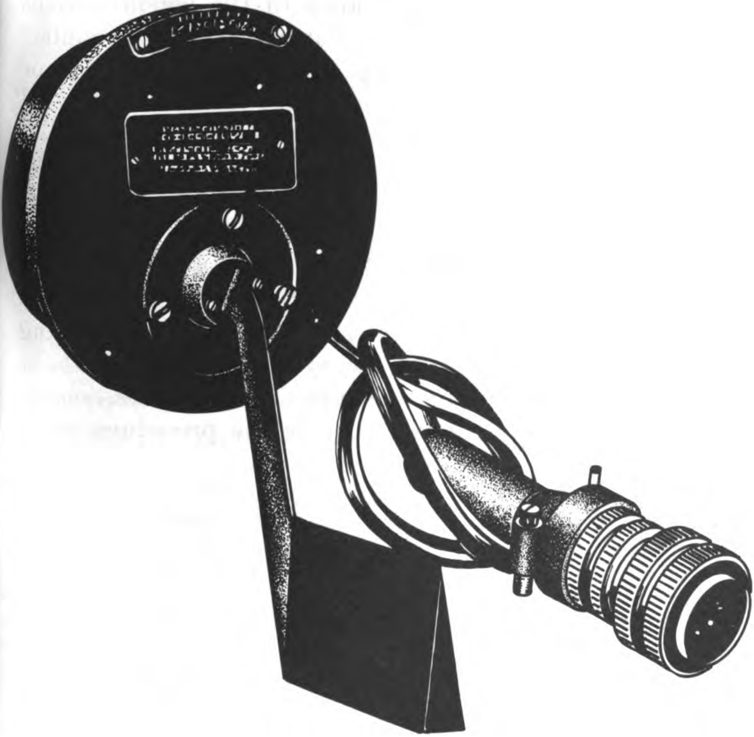


Figure 7–26.—Vane type relative wind transducer.

unit is parallel to the aircraft plane of symmetry. Its output is also fed to a fire control computer where it is combined with other flight data.

The angle of attack and angle of skid transmitters are equipped with electrical heaters to permit ice-free operation under all environmental conditions.

VANE TYPE.—The vane type of relative wind transducer performs the same functions as the probe type just discussed. However, it is somewhat simpler in its construction with all units having two potentiometers regardless of their use.

It should be noted in figure 7–26 that the wind vane is attached to the base unit where the probe appeared in the previous type. The vane will aline itself with the airstream, positioning the wiper arms of the potentiometers. The unit is constructed so that the vane is counterbalanced, permitting mounting in either the vertical or horizontal plane. It is also equipped with an electrical heater to prevent icing. As in the probe type, the output is fed to the fire control computer for the solution of the fire control problem.

Maintenance

Maintenance of the relative wind transducers by the Aviation Fire Control Technician is limited to checking their operation and replacing faulty units. The *Handbook of Service Instructions* for the transducer or its associated fire control equipment will prescribe the procedure to be used.

QUIZ

1. The axis on which a gyro rotor spins is the
   a. spin axis
   b. tilt axis
   c. servo axis
   d. torque axis
2. The gyro axis about which the disturbing force is applied is the
   a. spin axis
   b. servo axis
   c. tilt axis
   d. precession axis
3. The axis a gyro moves about as a result of an applied force is the
   a. spin axis
   b. servo axis
   c. torque axis
   d. tilt axis
4. A device which permits a gyro to incline freely in any direction and retain that position when the support is repositioned is a
   a. gimbal
   b. gimbal lock
   c. rotor
   d. physical stop
5. When a gyro's inner and outer gimbals become alined in the same plane,
   a. the gyro would operate normally
   b. gyro rotation stops
   c. a gimbal lock exists
   d. the gyro would be against a physical stop
6. The property of a gyro which causes it to maintain a fixed position in space is
   a. precession
   b. rigidity
   c. torque
   d. stabilization

7. In figure 7–12, if a downward force is applied to the right end of the gyro's spin axis, with the gyro spinning as shown, the right end of the spin axis will
   a. move down
   b. not move
   c. move toward you
   d. move away from you

8. A rate gyro is a device for detecting the ____________________ of an object.
   a. angular rate of change of position
   b. speed
   c. angular displacement
   d. acceleration

9. The rate of precession of a gyro
   a. is inversely proportional to the amount of torque applied
   b. is proportional to the amount of torque applied
   c. does not depend on the applied torque
   d. depends only upon its speed of rotation

10. A one-plane rate gyro could be used to detect a rate of change in
   a. elevation and azimuth simultaneously
   b. elevation, but never azimuth
   c. azimuth, but never elevation
   d. either elevation or azimuth

11. During acceleration, the pendulum of an accelerometer will
   a. oscillate
   b. appear to swing in the direction of the acceleration
   c. appear to swing in the opposite direction of the acceleration
   d. try to outrun the case

12. The output of the potentiometer type accelerometer is a signal that is ____________________ of/by the aircraft
   a. directly proportional to the G's pulled
   b. inversely proportional to the speed
   c. directly proportional to the speed
   d. indirectly proportional to the G's pulled

13. In the E-transformer accelerometer (fig. 7–7), ______________ is/are used to keep down oscillations.
   a. the E-laminated core
   b. fluid
   c. the leaf spring
   d. the stops

14. In a flux valve, the core is saturated for only ________________ degrees of each ________________ cycle of the input.
    a. 45; half
    b. 90; quarter
    c. 45; quarter
    d. 90; half

15. The output signals of the flux valve constitute ________________ data which represents the heading of the aircraft in respect to ________________.
    a. mechanical; true north
    b. electrical; true north
    c. electrical; magnetic north
    d. mechanical; magnetic north

16. The diffuser is designed to
    a. give accurate temperature information
    b. seal the resistive elements from the weather
    c. shield the enclosed temperature element from radiation
    d. act as an insulator

17. The principle of operation of the resistive temperature element is based on the fact that
    a. all metals have a constant resistance
    b. metals change their electrical resistance with changes in temperature
    c. metals provide electrical resistance which will not vary with temperature change
    d. resistance change can be easily read by the operator

18. The purpose of a temperature compensating device is to
    a. provide automatic correction for errors generated in the computer caused by change in temperature outside the computer
    b. provide automatic correction for errors generated in the computer caused by change in temperature within the computer
    c. provide automatic correction for errors in the computer caused by changes in temperature inside and outside the computer
    d. compensate for changes in circuit wiring when maintaining the equipment

19. At sea level pressure, a standard column of air is said to weigh
    a. 4.7 lbs.
    b. 7.4 lbs.
    c. 14.7 lbs.
    d. 17.4 lbs.

20. With an increase in air temperature, air density will
   a. decrease
   b. increase
   c. remain the same
   d. change a negligible amount

21. An absolute pressure pickup is a device used to
   a. determine air pressure relative to a predetermined standard
   b. measure changes in temperature
   c. measure the humidity of the air
   d. measure speed of movement of an air mass

22. In bombing or gunnery, airspeed is an important factor in determining the flight of a projectile. True airspeed is determined by a combination of
   a. speed over the ground, wind velocity, and altitude
   b. static air pressure (altitude), temperature, and impact air pressure
   c. static air pressure (altitude), speed over the ground, and temperature
   d. static air pressure (altitude), wind velocity, and temperature

23. Temperature is important to the fire control problem and is measured by various means, such as liquid temperature bulbs and resistive temperature devices. Temperature is used in calculating
   a. wind velocity
   b. airspeed
   c. range of bomb
   d. altitude

24. Relative wind transducers are used to detect
   a. launcher angle and angle of skid
   b. angle of yaw and angle of skid
   c. angle of attack and launcher angle
   d. angle of skid and angle of attack

CHAPTER 8

INTRODUCTION TO COMPUTERS

A computer is a device that performs mathematical calculations on input data to yield new and generally more useful results. The first computer, an abacus, was used by the ancient Greeks and Romans. It is a simple kind of manually operated device utilizing sliding beads; and if operated according to definite rules, can perform addition and subtraction. Computers found in use today range in complexity from the mechanical adding machine or slide rule to room size devices commonly called electronic brains.

The development of the computer has possibly contributed more to the advancement of fire control equipment than any one other factor. Without the use of complex computers, gun directors could not make continuous corrections for the many factors involved in the fire control problem.

COMPARISON OF DIGITAL AND ANALOG COMPUTERS

Computers may be divided into two main classifications based on the method of representing quantity; namely, DIGITAL and ANALOG. The digital computer expresses magnitude as a number of digits, and its accuracy is limited only by the number of significant figures provided. Increased accuracy can be obtained by utilizing more significant figures. The basic principles of operation of any digital computer is the same as that of the abacus or hand operated adding machine.

Modern digital computers are capable of providing extremely accurate results in a minimum of time. Future developments of computers for use in solving the bombing problem will probably be mostly digital. However, during the next five years, you can expect to see and maintain both analog and digital computers.

In the analog computer, numbers, or the variables, are represented by physical quantities that may be easily generated or controlled. These physical quantities may be represented by devices using degrees of rotation of a shaft, amplitude of voltages, distance, or some other physical quantity. The accuracy of the analog computer is determined by the percentage errors of the devices used; multiplied by the maximum quantity of the input variables. Analog computers are well adapted to solving fire control problems since they are capable of continuous operation necessary for constantly changing inputs.

COMPUTER TYPES

Computers may be further classified, based on their construction, as follows:

1. Mechanical.
2. Electronic.
3. Electromechanical.

MECHANICAL computers utilize mechanical quantities to represent the input and output values. They normally contain devices that add, subtract, multiply, or divide. Examples of these devices were discussed in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388. A complete mechanical computer will be discussed in detail in chapter 12 of this course.

ELECTRONIC computers utilize electrical units, such as voltage amplitude and phase, resistance, electrical pulses, and other electrical units to represent physical quantities. Computers of this type normally contain electronic and magnetic amplifiers, phase detectors, modulators, and demodulators. Chapter 10 of this course will discuss in detail the operation of an electronic fire control computer.

ELECTROMECHANICAL computers represent numbers or variables in both electrical and mechanical units. A typical application may employ both electrical and mechanical inputs to a servomechanism and have a mechanical output. A complete electromechanical computer will be discussed in chapter 11 of this course.

In actual practice, computers used in fire control equipment will not normally be of any one type, but will contain some features of all types. Their classification is based on the predominant type of computing device found in the equipment.

BASIC PRINCIPLES OF DIGITAL COMPUTERS

While analog computers use continuous physical quantities (such as voltage) to represent information, digital computers use a series of fixed steps or conditions to represent information.

High speed automatically sequenced electronic computers include simple arithmetic units which add, subtract, multiply, and divide. More complicated problems, such as differentiation, are reduced to arithmetic solutions. Information is stored in registers or memory units. Each register is identified so that a control system can guide the computer to perform a sequence of operations. Coded information which establishes the program, or routine, for solving a problem is fed into the input unit. Output devices convert computer solutions into readable answers.

Ordinary desk calculators use ten-tooth gears which can be positioned to represent every digit, 0 through 9, of our decimal system. For high speed computers there is no ideal electronic component which has ten positions. However, vacuum tubes which are ON or OFF (conducting current or not conducting) readily and reliably represent two positions. Fortunately, there is a notation system available, called the BINARY SYSTEM, which lends itself to the vacuum tube computer.

Binary System

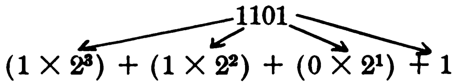
In a majority of the digital computers a binary system of coding is used. We are all familiar with the everyday usage of the scale-of-ten (decimal) representation of numbers. Take the number 8501 and determine how it is made up by powers of ten. In this number we are working with what is called the powers of ten, that is, with 10, 100, 1000, 10,000—or multiplied by itself as many times as desired. The number 8501 indicates:

$$(8 \times 1{,}000) + (5 \times 100) + (0 \times 10) + 1, \text{or}$$
$$(8 \times 10^3) + (5 \times 10^2) + (0 \times 10) + 1$$

In the decimal representation of a number, which is the form in common use today, the digits 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9 are used. In the binary representation of a number, only two digits (in various combinations), 0 and 1, are used.

In the binary system, a sequence of 0's and 1's indicates the presence of the number 2 (two) raised to some power. For example, the digits 1101 indicates $(1 \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + 1$. This would equal 13 in the decimal system. To help clarify, note the following representation of numbers:

Scale of Two



$$8 \quad + \quad 4 \quad + \quad 0 \quad + 1 = 13$$

Table 8–1.—Decimal to binary conversion.

Decimal	Binary	Decimal	Binary
0	0	13	1101
1	1	14	1110
2	10	15	1111
3	11	16	10000
4	100	17	10001
5	101	18	10010
6	110	19	10011
7	111	20	10100
8	1000	21	10101
9	1001	22	10110
10	1010	23	10111
11	1011	24	11000
12	1100	25	11001

Examine the preceding table for a moment. Consider the first four decimal numbers 0, 1, 2, and 3. To use the decimal system of numbering in a computing device, you would need to have four registers in order to record the information presented. Now, from the table, you see that the binary system needs only two digits, the 0 and 1, to represent the first four numbers. In this case, four conditions of information can be represented by the use of two digits.

You now should be able to see where an ON-OFF electronic system fits into the binary pattern very well. Suppose you wish to indicate the decimal number 3 in a computing function. This can be accomplished in the binary digital computer by representing it (from the table) as 11. The binary digits (11) would be represented in a relay system by both of the relays being in the closed (go) condition.

Once again referring to the table of decimal and binary numbers, you see that three digits of the binary system will enable you to represent eight pieces of information—with four digits, you can represent 16 pieces of information. By the time you have seven binary digits, you can represent 128 pieces of information.

Before a computer can operate properly and satisfactorily employ some numbering system, such as the binary system, it must have the ability to:

1. Remember data presented to it.
2. Make a choice based on previous results.
3. Make long chains of operations in short duration of time.
4. Determine if the answer is correct.
5. Determine when one problem is finished and when to start on another.

In order for the computer to be capable of the foregoing items, the proper information must be given to it. From this point on it will determine the answer by logical steps.

Input Unit

All the known data of a problem is injected into the computing system via the input unit. This unit, in the case of aviation fire control systems, will normally be data originating from error signals. These errors could be fed directly to the computer so that rapid corrections could be made.

The next job or function of the input unit is that of DECODING. The process of decoding information is an important function that must be carried out by the computer. Information received at the computer must be put into a form that is suitable for the operation of other circuits. This decoding is usually accomplished by any of the several types of demodulating circuits.

Logical Unit

The logical unit is where arithmetical operations of the computer are accomplished. The relay is a basic example of a device that easily notes the conditions of either GO or NO GO. Other units, however, are designed to simulate this action. These components that exhibit two stable positions are generally referred to as gates or gating circuits. The gate, as the name implies, permits or prevents the flow of current in a circuit.

Another important function that takes place in the logical unit is that of counting. In any computation, it is necessary to have a means by which the number of operations may be determined. This is the function of the COUNTER.

The counting function may or may not be a continuous operation in a computing system. When counting takes place depends on the state in which other components of the system are set; that is, it may be necessary to count a certain number of other operations that have taken place before some new operation is to begin.

Memory Unit

A memory unit stores information until it is called for in the computation of a problem. The memory unit is actually the backbone of the computer. It is in this portion of the digital computer where rapid advancement has been made. The use of small magnetic cores to form matrixes capable of storing large number of digits, yet physically small enough to be used in airborne equipment, has opened the door to the use of digital computers in aviation fire control equipment.

Output Unit

After all computations have been completed, there must be some means of presenting the answers to the operator. In an airborne fire control system the results of the computer may be used directly to position the steering error indication on a radar indicator or compute the release point in a bomb director system.

The technician should bear in mind that the previous discussion was included only as an introduction to the digital type computers. For detailed information on a specific type of computer you should consult the appropriate service manuals. You should also bear in mind that computers being designed and tested at the present time will have many changes and advancements over the basic digital computer designs discussed in this course. Some modern designs incorporate transistors, printed circuits, magnetic core type memory devices, and many other modern components or devices.

BASIC PRINCIPLES OF ANALOG COMPUTERS

A computer is a device for instrumentation of a mathematical problem. Therefore, all computers, regardless of type, perform some mathematical functions in solving their problem. The more complex analog computers used in aviation fire control equipments perform many mathematical functions, many of which are performed simultaneously. In this section we shall discuss some of the basic principles employed in complex analog computers. It should be realized that many of the manipulations to be discussed may result in the same end product. However, in order to solve its problem with sufficient accuracy in a minimum of time, a computer may employ several methods to solve similar equations of the complete fire control problem.

Mathematical Functions

Analog computers used in aviation fire control equipments are capable of performing the basic mathematical operations of summation, multiplication, and division. They are also capable of utilizing the more advanced fields of mathematics such as trigonometry and calculus. The circuitry or mechanisms used to perform the operations will be discussed in detail in a later chapter of this course. However, we shall discuss some of the aspects of their use.

SUMMATION.—The process of summation (addition and subtraction) can be accomplished with electrical or mechanical devices. Voltages are added or motions are added. Typical summation devices include: series and parallel electrical circuits, synchro units, and mechanical differentials.

MULTIPLICATION.—In multiplication where

$$a \times b = c$$

the product, c, is obtained by the multiplier, a, operating on the multiplicand, b or vice versa. Multipliers and multiplicands may be either voltages or motions. Multiplication in computers is performed by one of the following:

1. Volts × volts
2. Volts × motions
3. Motion × motion

Devices which perform multiplication, therefore, will be all electronic, electromechanical, or all mechanical. In an electromechanical device the terms to be multiplied may be represented by either voltages or shaft positions. The choice depends mainly on convenience. The output should be in a form easily used by the next step.

DIVISION.—In division where

$$c = \frac{a}{b},$$

the quotient, c, is obtained from the divisor, b, operating on the dividend a. Divisors and dividends can be either voltages or motions. Computer devices may take one of the following forms:

1. Volts ÷ motion

2. Volts ÷ volts
3. Motion ÷ motion

Electromechanical devices are most often used. Division is generally more difficult than multiplication because, as the divisor approaches zero, the quotient must approach infinity, a physical impossibility.

POWERS AND ROOTS.—Mathematical operations of raising a term to a power are expressed as

$$y = x^n$$

where n is the power or number of times x must be multiplied by itself. Conversely, extracting a root from a number is expressed as

$$y = \sqrt[n]{x} \quad \text{or} \quad y = x^{\frac{1}{n}}.$$

A variety of methods are used to solve these equations. A quantity may be squared (x^2) by multipling x by itself. The quantity may be raised to higher powers by continuing the multiplication process. Special curve-fitting potentiometers can be made to carry out the process. Mechanical motions can be made to obey square laws; for example, cams and spiral face gears. Logarithmic devices are also used and will be discussed later in this chapter.

TRIGONOMETRIC FUNCTIONS.—Trigonometric processes can be carried out with inductive resolvers, potentiometers, or all-mechanical devices. R–C phase shift networks are sometimes used to perform some trigonometric functions, such as vector addition. A typical equation to be solved in fire control is

$$x = r \sin \theta.$$

DIFFERENTIAL CALCULUS.—A value often needed in the solution of the fire control problem is the rate of change of one variable with respect to another. This is represented by the instantaneous slope of the curve showing the relation between the variables. The process of obtaining the rate of change of a quantity is known as differentiation, and the result is its derivative.

A typical application of differentiation in solving the fire control problem is the determination of range rate by taking the derivative of range in respect to time. Differentiation can be performed with mechanical, electromechanical or electronic devices.

INTEGRAL CALCULUS.—Integration is actually the process of summing up an infinite number of minute steps, each step being the product of the instantaneous speed for that step multiplied by the time interval of the step. In the solution of the fire control problem, computers must often solve for the cumulative effect of a quantity varying over a period of time. For example, we may want to know the horizontal range from a bomber to its target. By integrating the general equation for range rate and substituting the desired time limits, range from the plane to the target may be determined at any time during the bombing run.

Integration may be accomplished with mechanical, electromechanical, or all-electronic devices. Frequent application of integrators will be found in computers used in bombsights.

Equation Rearrangement

Although computers are capable of performing most of the methods of mathematics, many of the computers used in aviation fire control equipments have been designed around equation rearrangement.

Before considering the details of equation rearrangement, consider first why it is used. There are a number of requirements an analog computer must fulfill. Primarily, it must possess sufficient accuracy to solve a problem within the required limits. It must be constructed in a manner whereby it can withstand the stresses of airborne use and require a minimum of maintenance. It is also advantageous from the maintenance standpoint for a computer to use as many similar components as practicable, keeping the number of spare parts to a minimum. Therefore, you may find equipments that have rearranged simple equations from their simplest form to one that is more complicated mathematically for reasons not readily apparent to the technician.

One example of equation rearrangement was discussed in chapter 6 of this course. If you will recall, the following mathematical equation was to be solved:

$$J = \frac{R\,t_f}{R_f}$$

By a simple algebraic process, the equation was rearranged as follows:

$$\frac{R}{J} - \frac{R_f}{t_f} = 0$$

This arrangement of the equation is ideally suited for solving by use of a servomechanism. As you should recall, the servomechanism provides the necessary action to cancel any error signal producing a zero output.

Another example of equation rearrangement involves the use of logarithms. A computer problem may involve the multiplication and division of several quantities. Referring again to the equation

$$J = \frac{R\,t_f}{R_f},$$

it can be rearranged as follows:

$$\log_{10}J = \log_{10}R + \log_{10}t_f - \log_{10}R_f$$

The logarithm of each quantity may be found electronically by the use of specially designed networks. Once the equation has been changed into the logarithmic form, the computing is accomplished by simplified addition and subtraction of the quantities.

Magnetic amplifiers are especially well suited for solutions of this type. The results can be used frequently in the logarithmic form. However, the analog may also be found by use of a network giving an answer to the problem as originally stated.

Implicit problem solving.—The use of computers to solve complex problems does not always afford direct solution to all parts of the problem. Thus, the solution may be based on indirect or implicit methods.

Implicit problem solving may accomplish subtraction by means of addition, division by means of multiplication, the extraction of a square root by means of squaring, and integration by means of differentiation. The following is a comparison of explicit and implicit methods of problem solving.

	Explicit	*Implicit*
Subtraction	$c = a - b$	$c + b = a$
Square root	$c = \sqrt{a}$	$c^2 = a$
Division	$c = \frac{a}{b}$	$cb = a$

The use of the implicit function technique is found frequently in aviation fire control computers. There are numerous computations for which the implicit method may be more accurate or more convenient, based on the information available to the computer. Servomechanisms and amplifiers utilizing negative and positive feedback are well suited for instrumentation of implicit operations.

Representation of Quantity

For the purpose of this chapter, representation of quantity may be defined as that physical quantity used by an analog computer to represent a specific input quantity. Thus, for example, in an aviation fire control computer, a specific quantity, range from the gun platform to the target aircraft, may be identified with a d-c voltage fed to the analog computer for solution of the fire control problem.

The following list of representations may be encountered in fire control computers:

Mechanical

- Force
- Pressure
- Torque
- Linear displacement
- Angular rotation
- Linear velocity
- Angular velocity
- Linear acceleration
- Angular acceleration

Electrical

- Voltage
- Current
- Charge
- Impedance
- Frequency
- Phase

Table 8–2 gives some advantages and disadvantages of the two general types of representation. Regardless of the apparent advantages some methods of representation may have, all methods are found in fire control equipments.

Table 8–2.—Comparison of mechanical and electrical methods of representation.

Mechanical		Electrical	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Simpler and easier to understand. Few adjustments. Contain no electronic components subject to failure.	Subject to friction and wear. Requires precision components.	Flexibility. Replacements are normally standard parts. Accuracy. Weight. Speed of response.	Electronic parts failures. Components may change value causing drift.

Identity Operations

For the purpose of this chapter, an identity operation may be defined as any operation that does not change the mathematical quantity represented. Examples of identity operations are changes in scale factor, voltage level, impedance, and data representation.

CHANGE IN SCALE FACTOR.—Beofre discussing a change of scale factor, let us first define scale factor. In an analog computer, the scale factor is the ratio of the analog unit to the equation unit. Thus,

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units (physical)}}$$

Any change in analog units without a corresponding change in equation units will result in a change in scale factor. To illustrate this, we shall consider the following example:

A 10-volt positive d-c signal is selected to represent a range of 1,000 yards.

$$\text{scale factor} = \frac{+10 \text{ volts}}{1000 \text{ yards}} = 0.01$$

If the 10-volt signal is fed through a d-c amplifier having a voltage gain of 10, the analog unit is now equal to 100 volts. The scale factor is:

$$\text{scale factor} = \frac{+100 \text{ volts}}{1000 \text{ yards}} = 0.1$$

Thus, the scale factor was changed by the action of the amplifier.

CHANGE OF VOLTAGE LEVEL.—Computers, such as those utilizing addition and subtraction, must frequently change or shift the voltage level or reference to that level usable by subsequent components or units. A possible example of a shift in voltage level is found in direct-coupled amplifiers where the equipment is limited by the output of the d-c supply for the amplifier.

CHANGE OF IMEDANCE.—A change in output impedance may be required to match the various sections of a computer. This may be accomplished by the use of networks, and in some cases the use of cathode followers or other amplifiers employing feedback.

CHANGE OF SCALE.—Change of scale is accomplished by multiplication of the data by a fixed quantity. When the multiplier is less than one, simple networks of resistance, capacitance, or inductance may be used. When the constant of multiplication is greater than one, amplifiers whose gain has been accurately calibrated may be used.

CHANGE OF REPRESENTATION.—Fire control computers will normally utilize several methods of data representation. An example of multirepresentation was discussed in chapter 6 of this course under the heading "Turret Electrohydraulic Servo System." This computer utilizes a-c and d-c electrical voltages for its input data with its output converted to hydraulic pressure which, in turn, produces mechanical rotation. Most computers found in aviation fire control will utilize several methods of data representation.

COMPUTER PROBLEM

The information contained in this section is provided to widen the background of the Aviation Fire Control Technician and present information that will aid him in understanding the overall computer problem.

Computers, like other aviation equipment, must meet strict requirements on size and weight limitations. They must be constructed to withstand the vibrations and strains produced by combat maneuvers and still maintain a high degree of accuracy.

The requirements of supersonic speeds have dictated the extensive use of electronic circuits in computers. Many methods of equation solving may apparently offer simpler solutions to the equations found in the fire control computers. However, the designers must fulfill requirements that may not be readily apparent to the technician. The following requirements are among those considered in selecting methods of equation solving:

Accuracy
Time of response
Ease of operation
Ease of maintenance
Durability
Stability
Adaptability of inputs from other devices
Adaptability of outputs to other components of the system
Weight and space requirements.

QUIZ

1. The two main classifications of computers are
   a. digital and mechanical
   b. digital and analog
   c. analog and mechanical
   d. analog and electromechanical

2. The three main types of aviation fire control computers are
   a. mechanical, analog, electromechanical
   b. mechanical, electromechanical, digital
   c. electronic, mechanical, analog
   d. mechanical, electronic, electromechanical

3. In the majority of electronic digital computers the coding system used is the
   a. powers of ten system
   b. binary system
   c. decimal system
   d. metric system

4. The binary system is based on the number ______ raised to some power.
   a. 2
   b. 4
   c. 10
   d. 20

5. The number representation 1011 in the binary system is equal to ______ in the decimal system.
   a. 21
   b. 16
   c. 15
   d. 11

6. In the binary system 8 pieces of information may be represented by the use of ______ digits.
   a. 6
   b. 8
   c. 5
   d. 3

7. Arithmetical operations in a digital computer are accomplished in the
   - a. input unit
   - b. output unit
   - c. control unit
   - d. logical unit

8. The backbone or heart of a digital computer is the
   - a. input unit
   - b. logical unit
   - c. memory unit
   - d. control unit

9. The process of summation in an analog computer can be accomplished with
   - a. electrical devices only
   - b. mechanical devices only
   - c. electrical or mechanical devices
   - d. motions only

10. In an analog computer the mathematical operation of raising a term to a power is expressed algebraically as
    - a. $Y = X^n$
    - b. $Y = X$
    - c. $Y = \sqrt[n]{X}$
    - d. $Y = \frac{1}{X^n}$

11. In analog type computers, integration may be accomplished with
    - a. mechanical devices only
    - b. mechanical, electromechanical, or electronic devices
    - c. electromechanical devices only
    - d. electronic devices only

12. The implicit form of the explicit term $C = \sqrt{a}$ is
    - a. $C^2 = a$
    - b. $C^2 = a^2$
    - c. $a = \frac{c}{a}$
    - d. $a^2 = C$

13. Any operation in an analog computer that does not change the mathematical quantity represented is called a/an
    a. resultant operation
    b. identity operation
    c. summation operation
    d. integration operation

14. A change of scale is accomplished by multiplication of the data by a
    a. variable quantity
    b. nonlinear quantity
    c. fixed quantity
    d. variable proportional quantity

CHAPTER 9

COMPUTING INSTRUMENTS

In chapter 8 of this course, you were presented with a general introduction to computers. In this chapter the devices or instruments used to perform the various mathematical processes will be discussed.

As an Aviation Fire Control Technician, it will behoove you to concentrate on the theory of operation of each device. This information will be especially valuable in understanding the discussion of the various computer systems found in chapters 10, 11, and 12 of this course.

Computing devices have been divided into three groups; namely, LINEAR FUNCTIONS, NONLINEAR FUNCTIONS, and CALCULUS. Following this, the problems involved in grouping the devices to perform more complex problem solving is discussed. The technician should keep in mind that a discussion of this type will be valuable in understanding why some computers approach seemingly simple problems in a complex manner.

LINEAR FUNCTIONS

A linear function in mathematics is one that can be shown by straight lines on a graph. Linear functions include those functions that involve summation (addition and subtraction), multiplication, and division, but not those that involve squares, square roots, trigonometric functions and the like.

Summation

The process of summation can be accomplished with electrical, mechanical, or electromechanical devices. Voltages are added, motions are added, or voltages and motions may

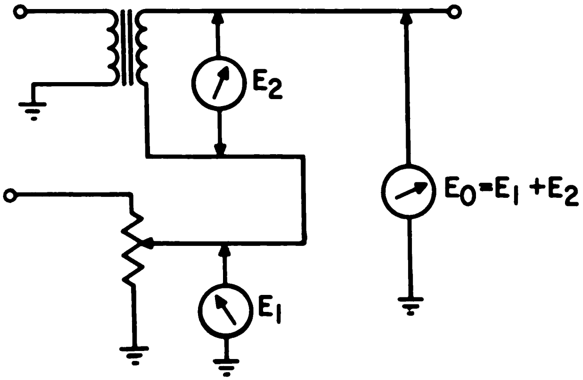


Figure 9–1.—Series addition.

be combined to give an output proportional to their inputs.

ELECTRICAL SUMMATION.—To simplify the presentation, both electrical and electronic summing devices will be discussed under this heading. The first device will be the series circuit in which the output voltage E_o is simply the series addition of the input voltages E_1 and E_2.

$$E_o = E_1 + E_2 \tag{1}$$

Only one of the input voltages can be grounded. Any others must be isolated from ground. This is illustrated in figure 9–1. Note that the secondary of the transformer is ungrounded, while the voltage of E_1 is from a grounded source. Isolating transformers must be carefully designed to minimize capacity coupling from primary to secondary winding, which would cause phase shift variations.

Series adding is primarily used when voltage sources are inductive units, such as synchros, tachometers, resolvers, etc., already isolated from ground. Series summation is also used when the attenuation of parallel summation networks cannot be tolerated.

When subtracting two a-c voltages by this method, they should be 180 degrees out of phase for correct results. Combining voltages that are not in phase or 180 degrees out of phase result in a quadrature voltage and consequently an error in the output.

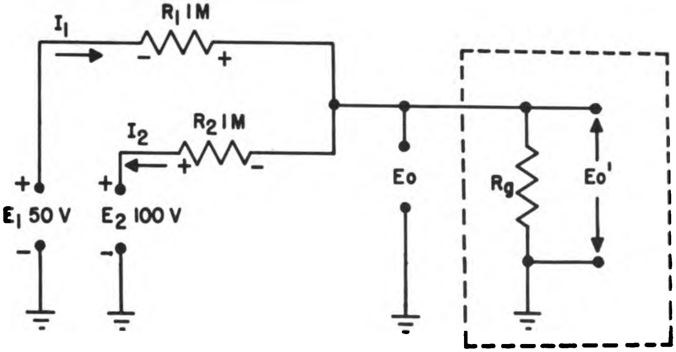


Figure 9–2.—Parallel summation network.

If d-c voltages are to be added in series, transformers cannot be used and a separate d-c power supply is required for each term or input to obtain isolated sources of voltage.

It should be remembered that the methods presented in this chapter are basic and many variations of these methods will be found in equipments.

A PARALLEL RESISTANCE NETWORK can also be used to electrically produce the algebraic sum of several input voltages. Voltages E_1 and E_2 are connected in series with two resistors R_1 and R_2 and terminated at a common junction as shown in figure 9–2. The voltage E_o is not the actual sum of the input voltages, but is proportional to that sum.

Using the values given in figure 9–2, let us now prove that the output voltage E_o is proportional to the inputs. If the voltage E_o feeds into an infinite impedance, there will be no load current. The circuit may now be considered as a series circuit, with

$$I_1 = I_2 \tag{2}$$

Then, since all branches are parallel,

$$E_1 + I_1R_1 = E_2 - I_2R_2 = E_o \tag{3}$$

Solving the currents in each part of equation (3) and substituting the results into equation (2),

$$\frac{E_o - E_1}{R_1} - \frac{E_2 - E_o}{R_2} = 0 \tag{4}$$

Solving equation (4) for E_o,

$$E_o = \frac{\dfrac{E_1}{R_1} + \dfrac{E_2}{R_2}}{\dfrac{1}{R_1} + \dfrac{1}{R_2}} \tag{5}$$

or, by further simplification,

$$E_o = \frac{R_2E_1 + R_1E_2}{R_2 + R_1} \tag{6}$$

Thus, the voltage E_0 has been solved for in terms of the sum of the two input voltages and their respective series resistors.

The voltage E_0 was solved for above by assuming a very high impedance load. If a grid resistor R_g is included, the voltage E_0 is determined by:

$$E_o' = E_o \cdot \frac{R_g}{\dfrac{R_1\ R_2}{R_1 + R_2} + R_g}$$

As pointed out previously, the voltage output is not the actual sum of the input voltages, but is proportional to that sum. The following example illustrates this proportionality:

E_1 = 50 volts E_2 = 100 volts
R_1 = 1 megohm R_2 = 1 megohm

Then, using equation (5),

$$E_o = \frac{\dfrac{50}{1 \times 10^6} + \dfrac{100}{1 \times 10^6}}{\dfrac{1}{1 \times 10^6} + \dfrac{1}{1 \times 10^6}}$$

$$E_0 = \frac{150}{2} = 75 \text{ volts}$$

If E_0 were the actual sum of the input voltages, the voltage output would be 150 volts. However, this difference in actual sum and proportional voltage can be compensated for by a change in scale factor.

When a difference between two terms is required (subtraction), a negative voltage is used to represent the quantity being subtracted (the subtrahend). Both the negative and positive voltages are fed to the parallel resistance network as previously discussed.

SCALE FACTOR.—Although addition has been explained as a summation of voltages, the computer's real job is to add physical units, such as feet per second or degrees per minute. The proper application of scale factors makes the addition of physical units of an equation possible. As pointed out in the last chapter,

$$\text{Physical or equation units} = \frac{\text{Analog units}}{\text{Scale factor}}$$

When the physical inputs to the analog computer are represented by voltages, the final solution in the proper units can be found only by dividing the summed voltages by the output scale factor. If the voltages E_1 and E_2 in figure 9–3 were chosen to represent 1,000 feet each, the scale factor for the input voltages would be 1 volt per 10 feet and should be written as $\frac{1 \text{ volt}}{10 \text{ feet}}$.

If the output physical units are to equal the sum of the input physical units, the scale factor at the output must be $\frac{1 \text{ volt}}{20 \text{ feet}}$. By using the transformation formula, the

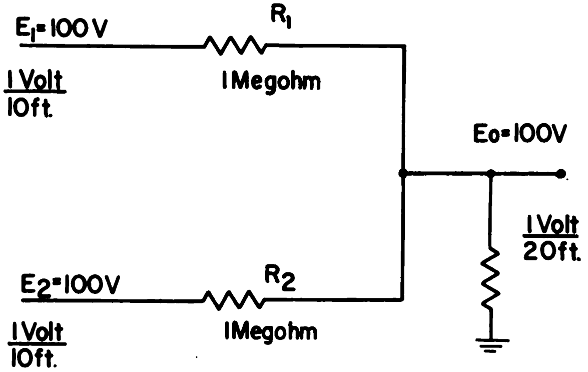


Figure 9–3.—Scale factors assigned to parallel resistor summation network.

sum of the physical units is

$$\frac{\frac{100 \text{ volts}}{1 \text{ volt}}}{20 \text{ ft.}} = 2{,}000 \text{ feet.}$$

In the examples discussed previously the input scale factors were identical. Consider the operation of the summing circuit shown in figure 9–4 if the input scale factors are different. In the equation $D_t = D_1 + D_2$, D_1 has a scale factor of $\frac{1 \text{ volt}}{10 \text{ ft.}}$ and D_2 is represented by the scale factor $\frac{1 \text{ volt}}{5 \text{ ft.}}$. Since the physical units per volt of the scale factors must add directly, the output scale factor is $\frac{1 \text{ volt}}{15 \text{ ft.}}$ From the example in figure 9–4, the correct answer for D_t is 2,000 feet. What values of R_1 and R_2 will supply the answer if the analog unit at the output is known and the output scale factor is also known? The analog unit is obtained by substituting in the following formula:

$$\begin{aligned} \text{Analog unit} &= \text{Equation unit} \times \text{Scale factor} \\ &= 2{,}000 \text{ ft.} \times \frac{1 \text{ volt}}{15 \text{ ft.}} \\ &= 133 \text{ volts} \end{aligned}$$

Referring to equation (6), it is apparent that R_1 cannot equal R_2 as in the previous example. It is permissible to

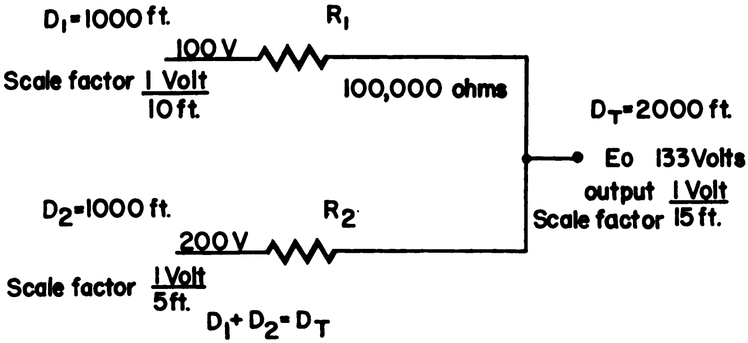

D₁=1000 ft.
R₁
100 V
Scale factor 1 Volt / 10 ft.
100,000 ohms
D_T=2000 ft.
Eo 133 Volts
output Scale factor 1 Volt / 15 ft.
D₂=1000 ft.
R₂
200 V
Scale factor 1 Volt / 5 ft.
D₁+D₂=D_T

Figure 9–4.—Addition with unequal scale factors.

select one resistance value arbitrarily, consequently R_1 may be set equal to 100,000 ohms, a typical value. Substituting known values in equation (6) and solving for R_2:

$$133\text{V} = \frac{R_2 \times 100 + 100{,}000 \times 200}{100{,}000 + R_2}$$

$$R_2 = 200{,}000 \text{ ohms}$$

As an Aviation Control Technician you will not be expected to compute component sizes or scale factors. However, it is of the utmost importance that you have a thorough understanding of scale factors in order that you may understand what is being accomplished in each stage of a computer and also how it is being accomplished.

In analog computers it is not always possible to apply the output of parallel resistor summation networks directly to subsequent circuits without getting nonlinear results because of loading. Loading is avoided by using an amplifier with a high-impedance input and a low-impedance output between the summation network output and the succeeding computer component. Either a cathode follower or an isolation amplifier can be used. For a detailed discussion on their operation, refer to chapter 5 of *Basic Electronics*, NavPers 10087.

ELECTRON TUBE CIRCUITS may also be used for the summing operation in analog computers. A typical difference amplifier is illustrated in figure 9–5. The input voltages, which are applied directly to the grids of the triodes, may

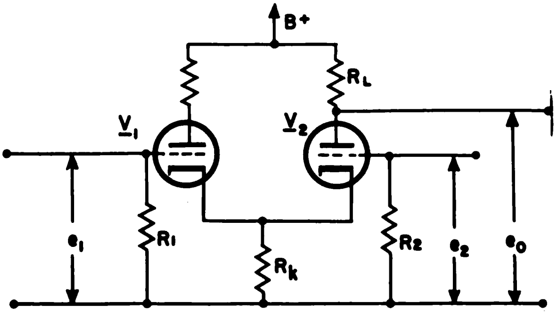


Figure 9–5.—A typical common cathode difference amplifier.

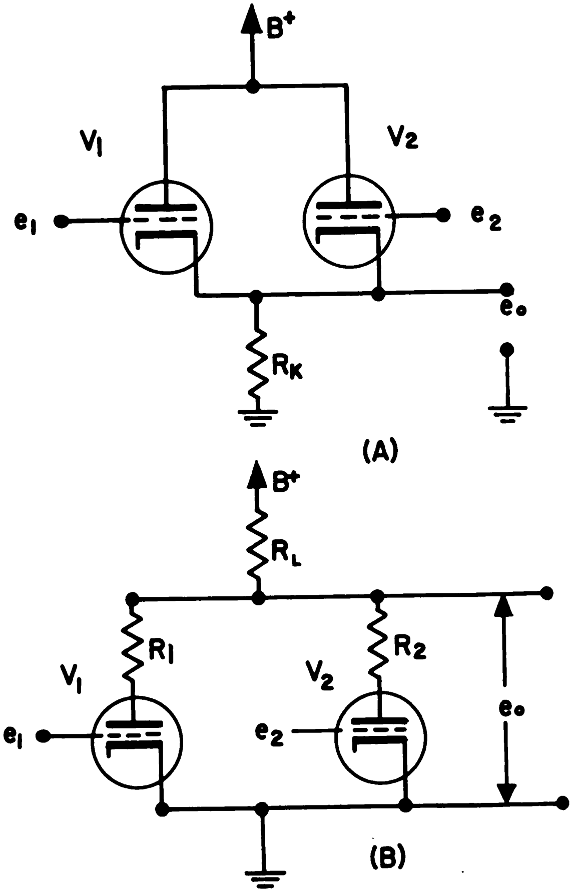


Figure 9–6.—Typical adding circuits.

be either negative or positive and need not be from an isolated source. The output voltage (e_o) is developed across the plate load resistor (R_L) of V_2 and is equal to

$$e_O = \frac{\mu\ R_L}{R_L + 2r_p}(e_1 - e_2)$$

It is assumed that V_1 and V_2 will have equal values for μ and within the tolerances required.

The output voltage is a proportional sum and is determined by the gain of the stage which is, in turn, determined by the circuit components. It should be remembered that a proportional sum output requires a change in scale factor as discussed previously.

A typical adding circuit is shown in (A) of figure 9–6. It also produces a proportional sum which is the sum of the individual tube's cathode current multiplied by the resistance of R_k. A variation of this adding circuit is shown in (B) of figure 9–6. This circuit offers an advantage of having small interaction between its inputs due to the large impedance of each stage.

MECHANICAL SUMMATION.—The device most commonly used for mechanical summation is the differential of which there are several types. Basically, the differential adds the revolutions of two shafts or subtracts the revolutions of one shaft from that of another shaft. The answer is given in the form of shaft rotations of a third shaft equivalent to one-half the sum or difference of the two inputs as the case may be. For a detailed discussion covering the operation of mechanical differentials, refer to the section on "Basic Mechanisms" in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388.

ELECTROMECHANICAL SUMMATION.—If the inputs or outputs of a summing operation cannot be physically brought together, a synchro system may be used. A chain of three synchro units consisting of a synchro transmitter, a synchro differential transmitter, and a synchro receiver adds or subtracts shaft rotations. If an output voltage rather than a shaft rotation is needed, the synchro receiver can be replaced with a synchro control transformer. Gear ratios may be added between the input shaft and the differential transmitter rotor to introduce coefficients. An example formula might be as follows:

$$\theta_O = \theta_1 \pm K\theta_2$$

The accuracy of a synchro summing system may be increased by using a two-speed synchro transmission system. For a discussion on the construction and theory of operation of synchro systems, refer to chapter 17 of *Basic Electricity*, NavPers 10086.

Multiplication

Multiplication is one of the mathematical operations which must be performed in a computer. It may be performed electronically by electron tube amplifiers or by magnetic amplifiers, electromechanically by potentiometers, and mechanically by devices called multipliers.

ELECTRONIC MULTIPLICATION.—A variety of multiplying circuits have been devised employing electronic amplifiers. However, every linear amplifier is a multiplier. It solves the equation

$$e_o = \mu e_g$$

which is identical to

$$y = kx$$

The grid signal e_g *is* multiplied by the tube amplification μ to give the product e_o. A typical amplifier as shown in figure 9–7 may be used for this purpose.

The available output voltage depends on the relation between the tube's internal impedance, r_p, and the load resistance, R_L. The actual output voltage in figure 9–7 is

$$e_o = \mu\, e_g \frac{R_L}{r_p + R_L}$$

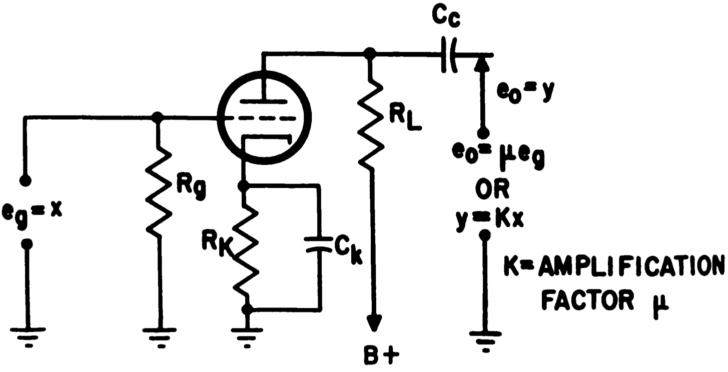


Figure 9–7.—Linear amplifier as a multiplier.

Where R_L is very large compared with r_p, the simpler formula $e_O = \mu e_g$ gives a good approximation of the output voltage.

Theoretically, the input signal voltage would be amplified by the same factor under all conditions. However, the transconductance, amplification factor, and plate resistance of the tube will vary with the applied voltage, and hence cause the circuit amplification to vary with the supply voltage. Therefore, d-c analog computers frequently employ negative feedback circuits. When a part of the output voltage of an amplifier is fed back to its input in such a manner as to oppose the input signal, it is called negative feedback. Feedback in amplifiers is discussed in detail in chapter 5 of *Basic Electronics*, NavPers 10087.

Utilizing sufficient amount of negative feedback and a high gain amplifier allows the actual gain of the circuit to be practically a function of feedback and almost inde-

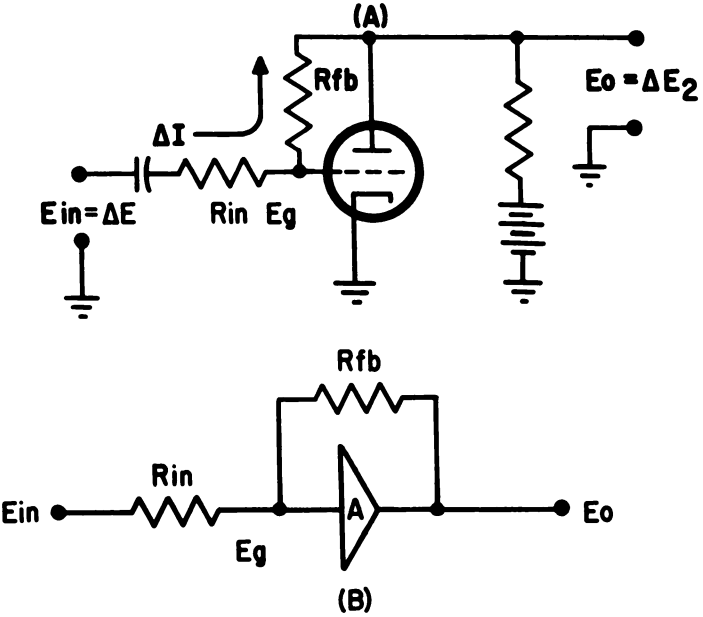


Figure 9–8.—Schematic diagram of a d-c amplifier with negative feedback.

pendent of tube variations. A typical amplifier circuit utilizing negative feedback is illustrated in figure 9–8.

Electron tube amplifiers are also capable of solving multiplication problems involving two variables as represented by the equation

$$e_o = kxy$$

Figure 9–9 illustrates a typical triode multiplication circuit. One variable input is applied as grid bias (preferably a d-c voltage) which establishes the gain of the stage. The other variable input is applied to the grid of the tube.

The output is a proportional quantity equal to the grid signal modified by the gain which is proportional to the variable bias voltage. This method is limited in scope and has limited accuracy due to variations in tube characteristics, contact potential, plate and filament supply changes, etc.

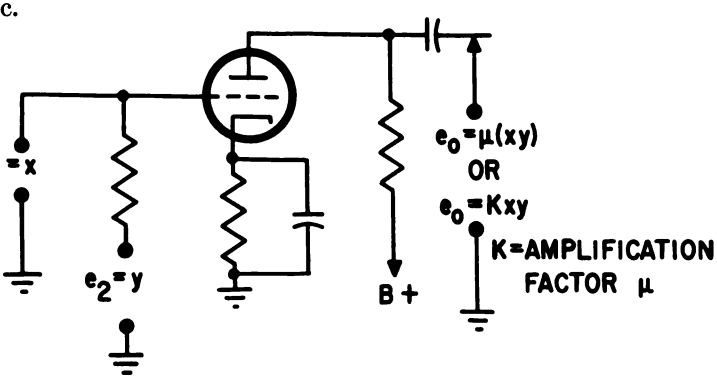


Figure 9–9.—Variable gain tube as a multiplier.

An improved multiplying circuit is shown in (A) of figure 9–10. Its operation is similar to the circuit shown in figure 9–9 except it employs the use of two separate grids. The voltage gain of the stage is controlled by the voltage on grid 3 as shown by the curve illustrated in (B) of figure 9–10. The gain of the amplifier is proportional to the voltage e_3 and may be expressed as follows:

$$A = k\,e_3$$

If the output voltage e_o is directly proportional to e_1, the

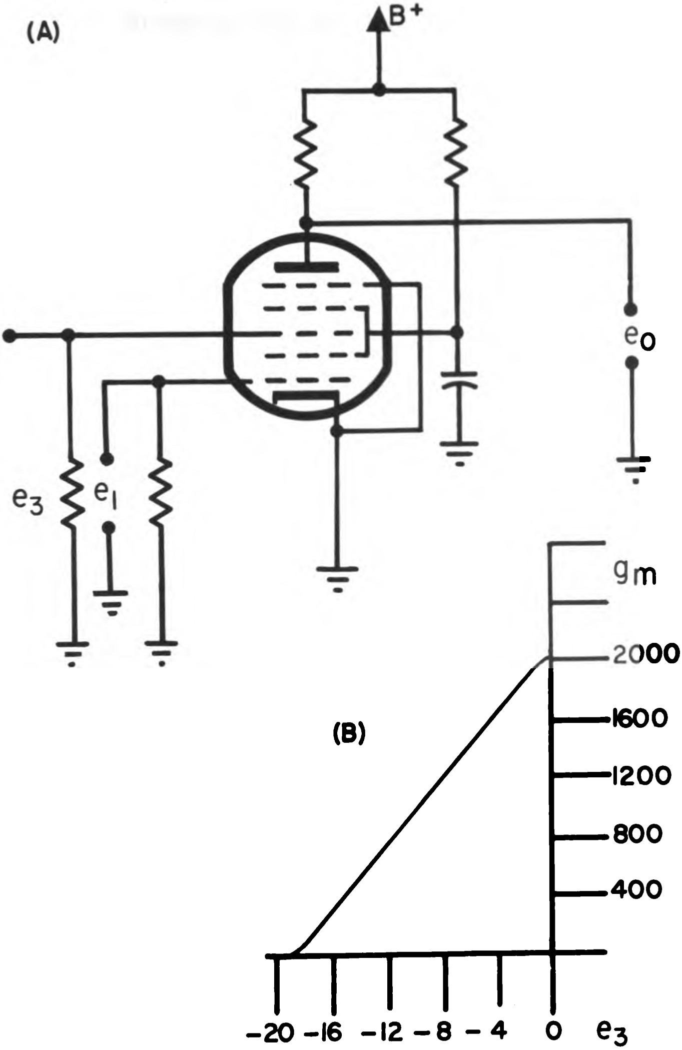


Figure 9–10.—A multielectrode tube used as a multiplier.

input signal, then

$$e_O = A\ e_1$$

Substituting for A, we have

$$e_O = k\ e_1\ e_3$$

The output is a proportional quantity as indicated by the constant *k*.

Magnetic amplifiers may also be used to multiply one factor by another. The saturable core reactor element in magnetic amplifiers makes the magnetic amplifier easily adapted for multiplying operations. Its amplification can be made proportional to a bias current over a limited range. However, accuracy is limited by variations in magnetic characteristics and winding resistance due to temperature variations.

Electromechanical multiplication.—Some of the electromechanical devices used for multiplication are potentiometers, synchros, and precision variable autotransformers. (Usually called by trade name; Variac.)

Precision potentiometers are frequently found used as multipliers in aviation fire control equipment because they are accurate, rugged, simply constructed, and inexpensive. They are equally well suited for a-c or d-c applications. Figure 9–11 illustrates a typical potentiometer type multiplier circuit.

The voltage occurring between the wiper and one end of the potentiometer is in reality the product of multiplying two quantities:

$$E_O = E_{\text{in}}\,\theta$$

One quantity is the voltage impressed across the resistor element, and the other is the position of the wiper. When E_{in} is 100 volts and θ is 100 percent, E_O is equal to 100 volts. If θ is 50 percent of full shaft rotation, E_O is equal to 50 volts.

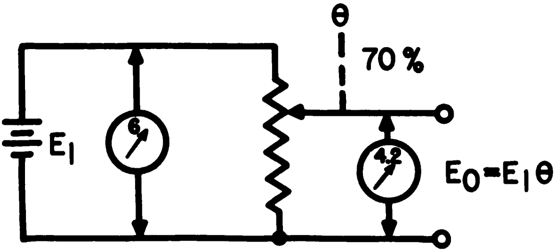


Figure 9–11.—Potentiometer type multiplier circuit.

A grounded center tap on the potentiometer winding permits either positive or negative output, depending upon the polarity of the input voltage and the position of the wiper shaft. Potentiometers are discussed in detail in chapter 9 of *Aviation Fire Control Technician 3*, NavPers 10388. The primary disadvantage of the potentiometer type multiplier is that a quantity cannot be multiplied by a factor greater than one.

AUTOTRANSFORMER multiplication is identical with potentiometer multiplication except that the input voltage must be a.c. The input impedance of an autotransformer is high, and its regulation under load variations is very good due to the low d-c resistance of the winding.

The low output impedance of the variable autotransformer permits it to be connected directly to other transformers, potentiometers or inductive resolvers, without intervening isolation amplifiers.

MECHANICAL MULTIPLIERS.—Mechanical multipliers are primarily of four types; namely, screw, rack, sector, and cam. Their operation was discussed in detail in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388, and will not be discussed in this course. It is recommended that this portion be reviewed prior to studying chapter 12.

Division

Instrumentation of division problems in an explicit form is generally difficult to perform. However, division can be accomplished by taking the reciprocal of the divisor and multiplying it by the dividend. This allows the use of less complex multiplication devices, a method normally found in aviation fire control equipments.

ELECTROMECHANICAL DIVISION.—A rheostat, or a potentiometer, connected as a rheostat in a voltage divider circuit provides a means of dividing a voltage by a shaft position. The voltage divider is an extremely simple method of dividing. The input voltage is applied to one end of the rheostat, and the second input is the shaft position of the rheostat. Figure 9–12 illustrates the operation of a divider network.

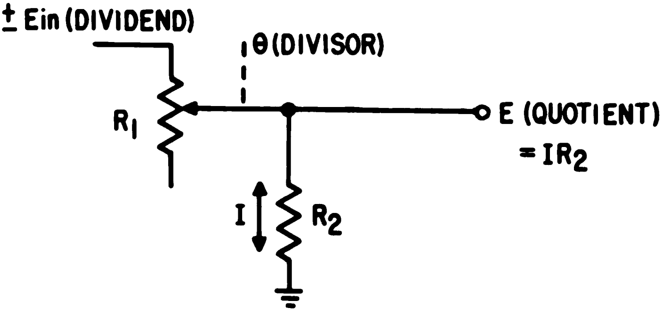


Figure 9–12.—Rheostat divider network.

Since the shaft position of the movable contact controls the series resistance, current is a quotient of voltage divided by the circuit resistance. The quotient can be obtained as a voltage across the fixed resistor R_2, in series with the rheostat. As in any analog system of division, the divisor cannot go to zero since the quotient would then become infinity. R_2 limits the current, and its value establishes the range of the divisor.

A voltage E_{in} is made proportional to one input and the resistance $R_1 + R_2$ is proportional to the second input.

The current $I = \dfrac{E_{in}}{R_1 + R_2}$

The output voltage $E_o = \dfrac{E_{in}}{R_1 + R_2} R_2$

or $\dfrac{E_o}{R_2} = \dfrac{E_{in}}{R_1 + R_2}$

Substituting K for the constant value of R_2, and θ for the variable R_1:

$$\frac{E_o}{K} = \frac{E_{in}}{\theta + K}$$

The term K affects E_o only as a scale factor change. It affects θ only as a shift in value. Consider as an example the equation for determining angular velocity $\omega = \dfrac{S}{D}$ radians per second where S is linear velocity in feet per second; D is slant range with limits from 600 to 6,000 feet.

The value of R_2 represents the minimum range of 600 feet and $R_1 + R_2$ represents 6,000 feet. Therefore,

$$\frac{R_1}{R_1 + R_2} = \frac{600}{6{,}000} \text{ or } R_1 = 9R_2$$

A value for R_2 is selected which will produce reasonable current limits over the range of E_{in}. If E_{in} has a range from 0 ± 100 volts and the maximum current which may be drawn is 10 ma., R_2 becomes 10,000 ohms. R_1 will then vary from 0 to 90,000 ohms as D goes from 600 to 6,000 feet. E_0 at maximum speed and minimum range will be as follows:

$$\frac{100 \times 10{,}000}{10{,}000} = 100 \text{ volts}$$

When $D = 6{,}000$ feet, maximum speed will produce an angular velocity output represented by an output voltage E_o of:

$$\frac{100 \times 10{,}000}{90{,}000 + 10{,}000} = 10 \text{ volts}$$

Since R_1 cannot have a negative value, this method is only suitable when the divisor has the same polarity at all times.

Servomechanisms are often used for implicit division in aviation fire control computers. Division is usually represented by the equation

$$x = \frac{y}{z}$$

However, in order to utilize a servomechanism the equation is rearranged as follows:

$$y - xz = 0$$

The instrumentation of the equation is shown in figure 9–13. Its operation is similar to the servo system discussed in chapter 6 under the heading "Computer Servo System." For a detailed explanation of its operation, you should review the previously mentioned section of chapter 6. However, we shall briefly discuss the inputs and output of the system. The system has two electrical inputs, the amplitude and polarity of each are determined in other units. The voltage y is fed directly to the error detector while the voltage z is multiplied by the shaft

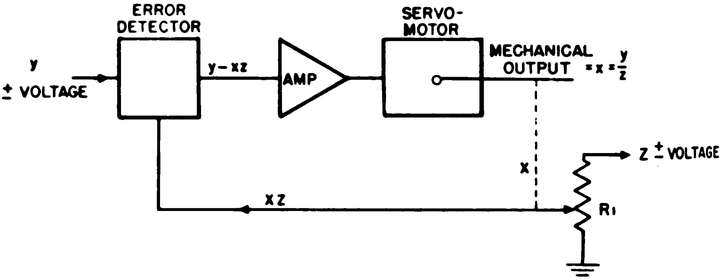


Figure 9–13.—Division with a servomechanism.

position x, with the product xz being fed to the error detector for comparison with the input y. As in any servo system, the error voltage drives the servomotor in the direction that will cancel the error voltage giving a zero output.

ELECTRONIC DIVIDERS.—Electronic division can be performed by inserting a vacuum tube in place of the variable resistor in a rheostat divider network. The plate resistance of the tube is varied by the voltage applied to the control grid. Figure 9–14 illustrates the circuit of an electronic divider. The cathode resistor performs the same function as R_2 in figure 9–12. As in other electronic circuits, the circuit must be operated within limits determined by its components.

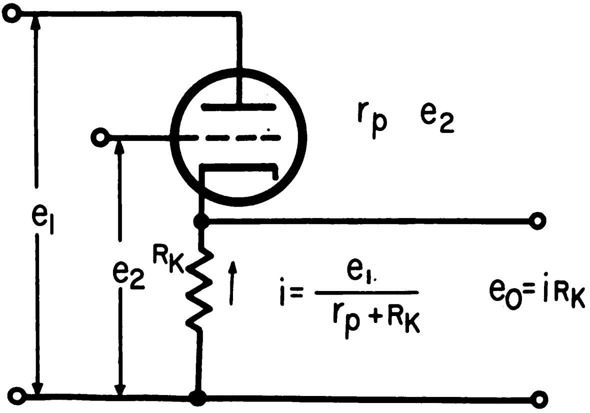


Figure 9–14.—Electronic divider circuit.

Mechanical division.—Mechanical division may be accomplished by using mechanical multipliers by merely interchanging one input and the output. Mechanical multipliers were discussed in detail in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388.

NONLINEAR FUNCTIONS

Under this heading, instrumentation of various mathematical operations, such as raising a term to a power or extracting a root of a term, will be discussed. It shall also include the generation of trigonometric functions.

Most of these operations can be performed by mechanical, electromechanical, and electronic devices. However, one type of device may be more adaptable to a particular operation than another when considering the requirements of an aviation fire control computer. Nonlinear mathematical operations may also be performed by special applications of linear devices previously discussed. For example, a term may be raised to the second power by simply multiplying it by itself, using some type of linear multiplier.

Powers and Roots

A variety of methods are used in aviation fire control equipment for solving problems involving powers and roots. The most common method utilizes electromechanical principles.

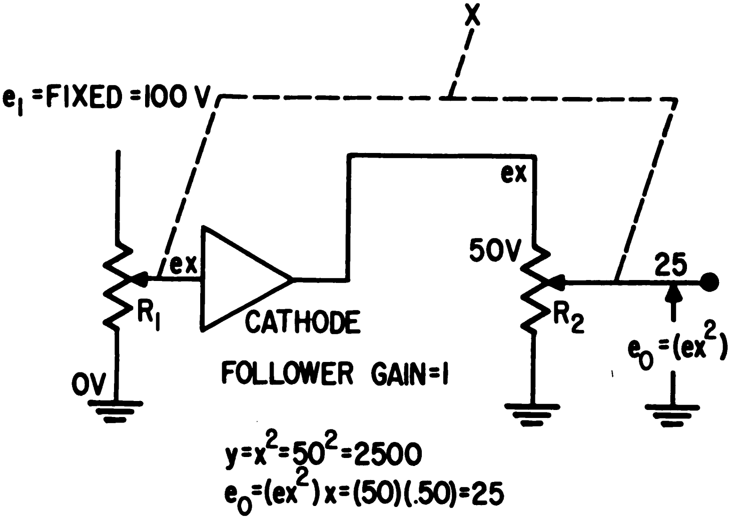
Powers.—The solution of the fire control problem requires use of devices capable of raising terms to a power. In most cases, the term is raised to the second power (squared).

There are several electronic circuits capable of performing this operation. Perhaps the simplest of the group is a modified use of the multiplying circuit previously discussed and shown in figure 9–10. By applying the input value to both grids 1 and 3, the output voltage will be proportional to the square of the input.

Another electronic circuit capable of squaring is called the squaring amplifier. It consists of a paraphase amplifier with its outputs driving push-pull triode amplifiers. Its output is also proportional to the square of the input requiring a change in scale factor.

A common ELECTROMECHANICAL method of raising a term to a power is by successive multiplication with potentiometer multipliers. Potentiometer type multipliers have been discussed previously and shall not be reviewed in this section.

When the equation is $y = x^2$, ganged potentiometers may be used, provided x is the common shaft position of the potentiometers. This circuit is illustrated in figure 9–15. The fixed voltage into R_1 is made proportional to the maximum value of x. The voltage (ex) at the variable tap of R_1 is at all times proportional to x. The voltage at the tap of R_1 is fed through an isolating circuit to R_2. The maximum voltage to R_2 is equal to ex. This voltage is again multiplied by x and the output voltage at the variable tap of R_2 is equal to x times ex, or ex^2. The variable x may be raised to the third power, and so on, by adding additional potentiometers.



$$y = x^2 = 50^2 = 2500$$
$$e_0 = (ex^2)x = (50)(.50) = 25$$

Figure 9–15.—Powers by successive multiplication.

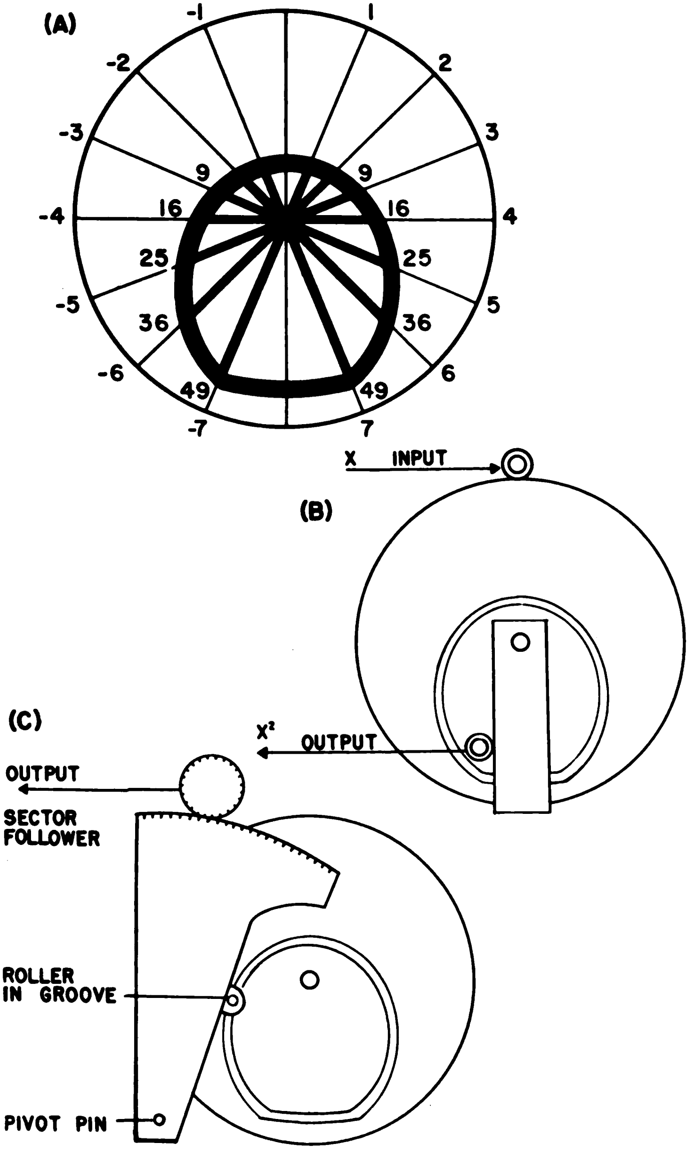


Figure 9–16.—Squaring cam.

The cam is a MECHANICAL means of raising a term to a power. However, their use is normally limited to squaring of a term. Figure 9–16 illustrates a basic square cam and two types of followers used to transmit its output to other devices. The input positions the cam as indicated by the numbers around the outside periphery of the cam. The follower then registers the output value in accordance with its position in the groove or on the curved surface. The output of a square cam will always be of a positive value.

ROOTS.—The root of a term may be extracted by either electromechanical or electronic devices. In fact, any multiplying or integrating device capable of raising a term to a power and also capable of producing inverse functions can be used to produce roots. However, in aviation fire control equipment the extracting of roots is normally accomplished by electromechanical devices. A typical device of this type is shown in figure 9–17.

An ELECTROMECHANICAL device for extracting the root of a term or number is the servomechanism feedback loop which utilizes ganged potentiometers as shown in figure 9–17. The equation $y = \sqrt[n]{x}$ may be written as $x - y^n = 0$ by raising both sides to the nth power and transposing the y term. Now the term is in required form for servomechanism instrumentation.

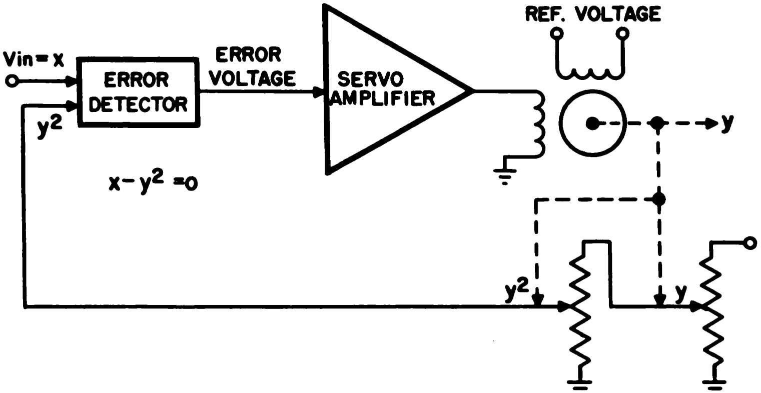


Figure 9–17.—Square root servomechanism.

Square root is solved by multiplying the output quantity y by itself and using this value as the feedback term. The output of the square root device is in the form of a shaft position, y.

Trigonometric Functions

Trigonometric processes can be carried out with inductive resolvers, potentiometers, or all-mechanical devices. Electronic networks consisting of R and C are also sometimes used to perform some trigonometric functions, such as vector addition.

The trigonometric functions most often used in fire control equipment are sine and cosine. However, the four remaining functions may be computed based on the sine and cosine.

NOTE: Those persons not familiar with the trigonometric identities should study chapter 5 of *Mathematics*, Vol. 2, NavPers 10070–A, and chapter 6 of *Advanced Mathematics*, NavPers 10071.

ELECTROMECHANICAL DEVICES.—The INDUCTIVE RESOLVER is one of the most common electromechanical devices used to generate trigonometric functions. It is basically a right triangle solver, using windings to represent the sides and magnetic flux to represent the hypotenuse. The shaft rotation corresponds to one of the angles of the right triangle that is to be solved.

The construction is very similar to a synchro, except that both the rotor and stator have two windings oriented 90 degrees from each other as shown in figure 9–18. Their primary use is to resolve a voltage into two components at right angles or to combine two component voltages into their vector sum.

When a rotor winding is parallel to one stator winding, the device acts as a one-to-one transformer. As the rotor winding is rotated, the voltage induced depends on the sine of the angle of rotation times the applied voltage.

$$E_0 = E_{in} \sin \theta$$

Figure 9–19 illustrates the action of the inductive resolver for three positions.

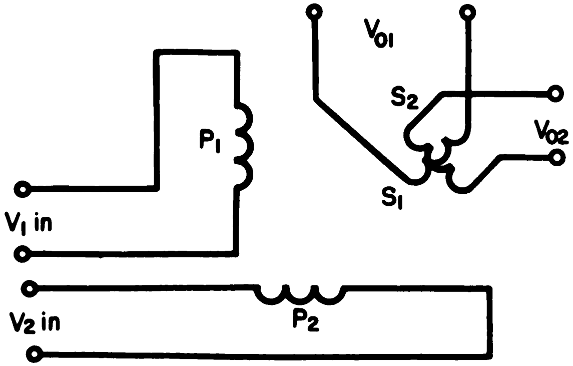


Figure 9–18.—Inductive resolver diagram.

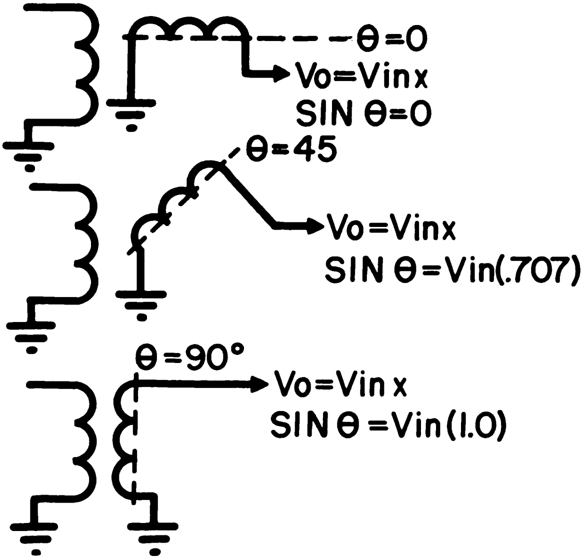


Figure 9–19.—Inductive resolver action.

If the second rotor winding, as shown in figure 9–20, is at right angles to the first winding, its output will correspond to the cosine of the rotation angle, since

$$\cos \theta = \sin(\theta + 90^\circ)$$

Resolvers are low-impedance devices. Isolation or booster

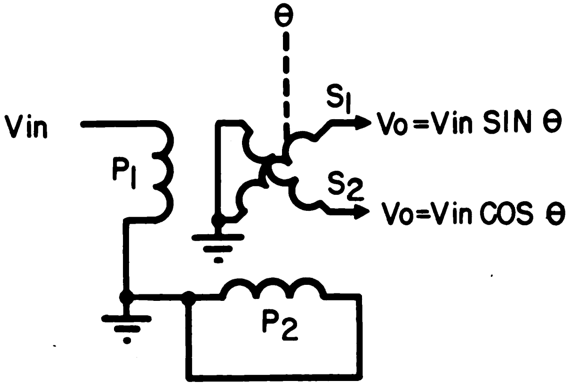


Figure 9–20.—Inductive resolver with two-phase winding.

amplifiers are generally used as driving circuits if the inductive resolver input signal originates in a high-impedance source, such as a potentiometer. Isolation amplifiers have a low output impedance and can correct for any undesirable phase shift developed in the resolver. Since inductive resolvers operate only with a-c voltages, they cannot be used in d-c analog computers.

Some operations of fire control computers require that the computer be capable of transforming data from a polar to a rectangular coordinate system. If the position of a point or object is defined by a vector, the polar dimensions of the vector may be converted to rectangular coordinates. The vector quantity, distance r and angle θ, may be resolved into horizontal and vertical distances, x and y respectively, with a 2-phase inductive resolver. By feeding a voltage representing the distance r into the one stator winding and rotating the rotor shaft correspondingly to θ, voltages representing x and y are produced at the rotor windings as shown in figure 9–21.

Sine and cosine POTENTIOMETERS are specially designed devices for the selection of a voltage that is indicative of either the sine or cosine of an angle. Output voltages proportional to the product of the input voltage and either the sine or cosine of the angle through which the shaft is

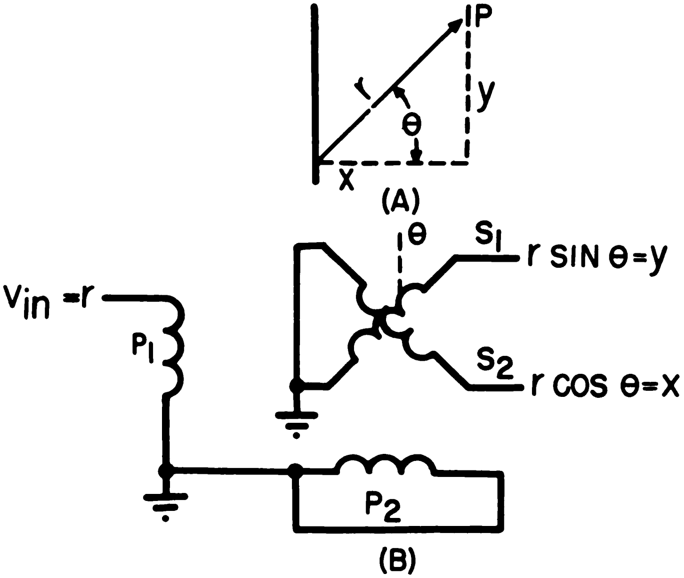


Figure 9–21.—Polar to rectangular transformation.

rotated can be obtained from the specially designed potentiometers. These potentiometers were discussed in detail in chapter 9 of *Aviation Fire Control Technician 3*, NavPers 10388.

MECHANICAL DEVICES.—The TANGENT CAM is a commonly used trigonometric device in mechanical computers. However, its operation must be limited to small angles due to the fact that the tangent of an angle ranges from zero to infinity. The tangent cam does not differ greatly from other cams except that the groove is cut differently and the output is a function of the input angle and is the tangent of that angle. Figure 9–22 illustrates a tangent cam.

COMPONENT SOLVERS and VECTOR SOLVERS are devices that are also used in mechanical computers. The name of each indicates its respective method of operation and, as in inductive resolvers, one is nearly the reverse of the other. The component solver takes a vector of some magnitude and angular position and resolves it into its two rectangu-

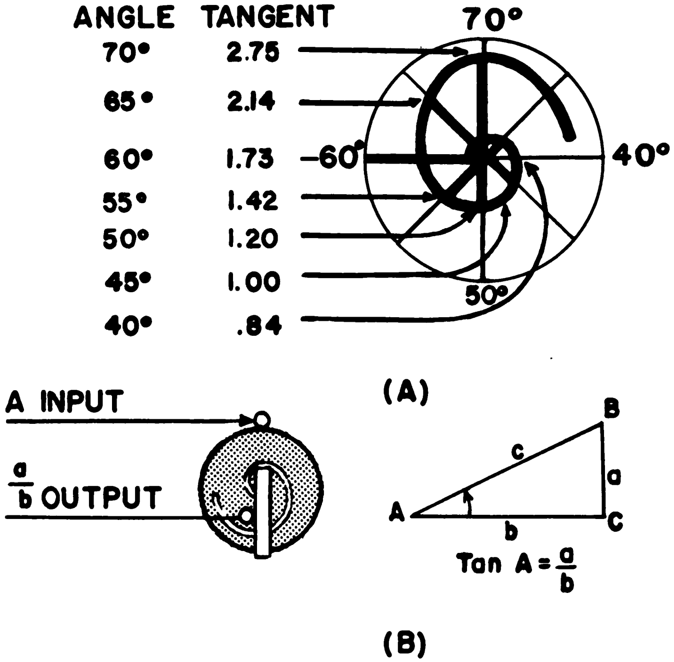


Figure 9–22.—Tangent cam.

lar components. The vector solver performs just the opposite operation by taking the two rectangular components and solving for a vector at an angular position.

There are several types of component and vector solvers. However, this discussion will be limited to the screw type component solver. The device consists of a vector gear, two racks, two output gears, two input gears, and a screw and pin assembly. The speed input gear drives a gear train which causes the screw to turn. As the screw turns, it drives an assembly carrying the pin, thus changing the length of the vector which is proportional to the input component, such as *r* (slant range). (See fig. 9–23.)

In this type component solver the pin can travel nearly the full width of the vector gear. From the pins zero or center position it can be moved in either of two directions which corresponds to positive or negative directions.

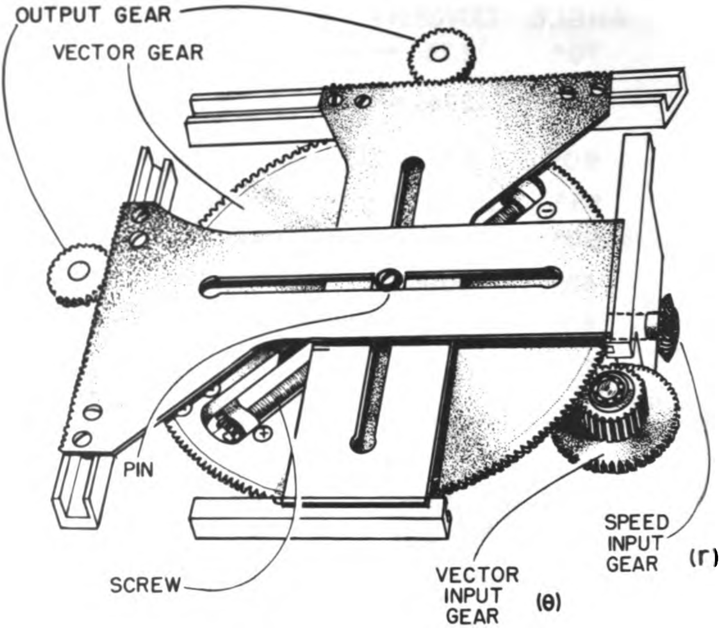


Figure 9–23.—Component solver.

The vector input gear drives the vector gear in the desired angular direction indicating target position, θ. The pin positions the racks as it moves along the slot, thus resolving the vector into its components. Therefore, it solves for the desired quantities as shown in figure 9–24.

Logarithms

The application of logarithms to perform multiplication and division was briefly discussed in chapter 8 of this course. A study of logarithmic processes in *Mathematics*, Vol. 2, NavPers 10070–A, will indicate the ease of raising a term to a power or extracting a root of a term with the use of logarithms. However, in this section we are primarily concerned with devices for obtaining the logarithm of a term.

Diodes and contact rectifiers under some conditions have nearly exponential variations of current with voltage, or

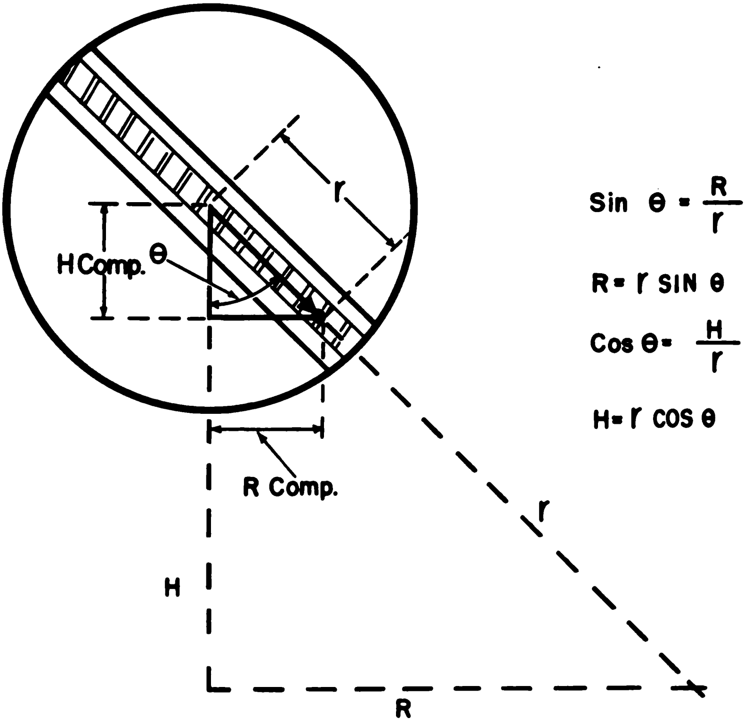


Figure 9–24.—Problem solution by component solver.

logarithmic variation of voltage with current. However, the operating limits of a single diode are surpassed by the requirements of most fire control computers. This limitation necessitates the use of circuits such as shown in figure 9–25 to produce logarithmic functions.

The purpose of this circuit is to produce an output voltage that is proportional to the logarithm of the input current. Referring to figure 9–25, it should be noted that R_2, R_4, and R_6 form a voltage divider network. The cathode of each rectifier is connected through a resistor to some point on the voltage divider. This effectively acts as bias, causing each rectifier to be cut off until its plate reaches a potential higher than its cathode.

As the input current is applied, current flow will be up

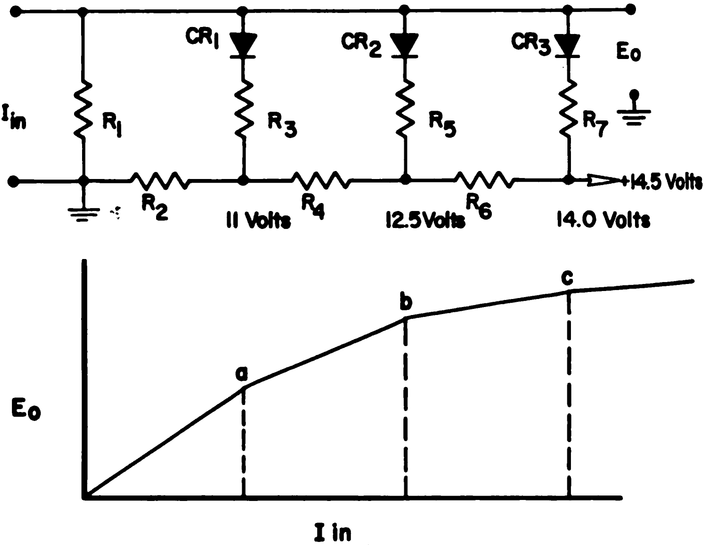


Figure 9–25.—Typical logarithmic shaping network.

through R_1 producing an output voltage proportional to the current. ($E = IR$) As the current, hence the voltage drop across R_1, becomes great enough, the top of R_1 will become positive enough to bring CR_1 into conduction. As soon as CR_1 conducts, it effectively places R_3 in parallel with R_1, lowering the total resistance and producing less voltage drop for a given increase in input current. This accounts for the bend in the curve at point *a*. The circuit response curve illustrates how the slope is successively reduced as additional rectifiers come into conduction. It should also be noted that an increased number of rectifiers could result in a more perfect curve. However, the circuit shown provides an output well within the tolerances required for fire control computers.

There are several means available of obtaining the antilogarithm of a quantity. This may be done either by employing an exponential characteristic directly or by the use of a feedback loop. Implicit methods may also be used such as taking the derivative of the term eliminating the logarithm in the equation.

CALCULUS

Calculus is a branch of mathematics that deals with the rate of change of a function and with the inverse process which is the determination of a function from its rate of change. The process of determining the rate of change of one variable with respect to another is called DIFFERENTIATION or differential calculus. The process of determining the sum of many minute quantities is referred to as INTEGRATION or integral calculus.

Differentiation

Before going into the actual process of differentiation, let us briefly discuss the terminology to be used. Consider the equation $x = \mathrm{f}(y)$. It should be read as: x equals a function of y. If the derivative of x is taken with respect to y, then it would be written as:

$$\frac{dx}{dy} = \frac{d\,[\mathrm{f}\,(y)]}{dy}$$

which, in notation form, is

$$\frac{dx}{dy} = \mathrm{f}'\,(y)$$

$$dx = \mathrm{f}'\,(y)\,dy$$

By now it should be obvious that the prime indicates the first derivative of the function.

Although y represents any variable, we are generally interested in the derivative with respect to time. The derivative of a quantity with respect to time can be thought of as the time rate of change of that quantity. For motion along a straight line, for example, the derivative of the distance traversed with respect to time is the velocity or the time rate of change of distance. Similarly, the derivative of a voltage with respect to time is the time rate of change of that voltage. Figure 9–26 shows a graphical representation of the derivative of a voltage. If a voltage E_{in} is changing at a constant rate as shown in (A) of figure 9–26, then the derivative E_o of that voltage has a constant value as shown in (B) of figure 9–26. A common symbol for the time derivative of a quantity is x.

ELECTRONIC DIFFERENTIATION.—The rate at which an in-

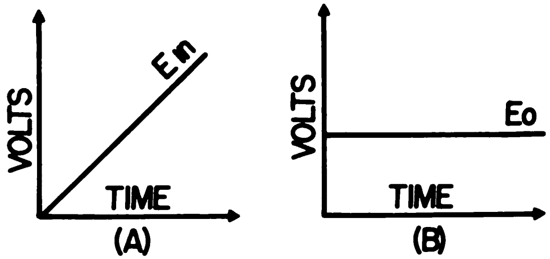


Figure 9–26.—Graphic representation of the derivative of a voltage.

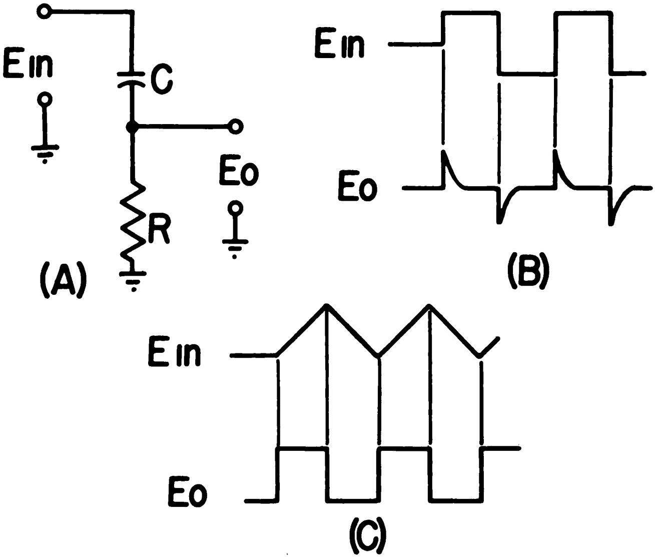


Figure 9–27.—Simple differentiating circuit.

put voltage is changing can be obtained from a simple series-connected resistor and capacitor circuit as shown in (A) of figure 9–27. Notice that the output voltage of this circuit appears across the resistor. With the proper values of R and C to provide a short RC time constant and with a square-wave input voltage E_{in}, the output voltage E_o will be that shown in (B) of figure 9–27. When the rate

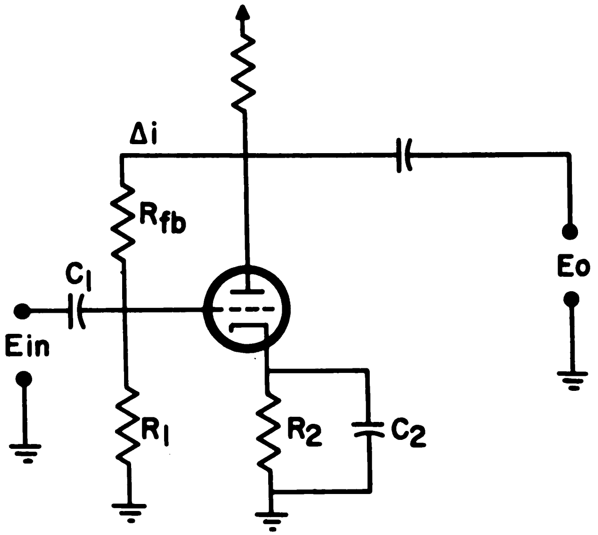


Figure 9–28.—Differentiating circuit employing a feedback amplifier.

of change of E_{in} is greatest, the value of E_o is greatest, and when the rate of change of E_{in} is zero, the output E_o tends toward zero. The derivative of a triangular wave or a saw-tooth wave is shown in (C) of figure 9–27. These facts illustrate that the output voltage is approximately equal to the rate of change (derivative) of the input voltage.

The primary disadvantage of the simple differentiating circuit is the time required for the output voltage to become equal to the derivative of the input voltage. Shortening the RC time constant to decrease this time decreases the amplitude of the output voltage.

A feedback amplifier differentiator is shown in figure 9–28. This type of differentiator is superior to the simple differentiator circuit, because its output voltage approximates the derivative of the input voltage in a much shorter time and with greater accuracy.

In the following discussion involving the application of a feedback amplifier, it is presupposed that the trainee has a thorough understanding of the theory of negative feedback amplifiers. Therefore, any trainee not possessing this understanding should study chapter 5 of *Basic Electronics*, NavPers 10087.

Before discussing the operation of the differentiator amplifier circuit, we shall establish the following conditions:

1. The amplifier must be biased so as to operate near the center of its linear range and not draw any grid current when operating within its specified limits.

2. The grid voltage will be near ground potential and will change only a very small amount when the input signal varies. This occurs because the feedback voltage tends to prevent any change in grid voltage.

3. Since the grid voltage will remain almost constant, any change in plate voltage due to an input signal will appear almost entirely across the feedback resistor causing a corresponding change in current through it. Therefore, the output voltage E_o is given by the formula

$$E_o = -\Delta i \, R_{fb}$$

Where E_o is the change in plate voltage (a-c component) resulting from an input signal applied to the grid.

Δi is the change in current flowing through the feedback resistor.

R_{fb} is the feedback resistor.

Let us now restate the above formula in more simple terms keeping in mind that a differentiator can only produce an output when there is a change in the input voltage. The amplitude of the output voltage (a.c.) is equal to the change in feedback current (a-c component) multiplied by the resistance of the feedback resistor. The negative sign is to correct for the polarity inversion of the amplifier.

Consider the action of the circuit with a constantly changing voltage applied. (See fig. 9–28.) For simplicity of explanation, consider a back-to-back saw tooth that is starting downward from its apex. As the negative going signal starts downward, electrons from the grid side of C_1 will start to flow through R_{fb} (electrons are attracted to the higher potential of the plate) causing the grid voltage to drop. This action reduces plate current causing a rise in plate voltage. However, a portion of the plate voltage increase is fed back to the grid causing it to rise in potential. (NOTE: Since the feedback voltage is only a small portion of the plate signal, the grid cannot come back to its initial voltage.) The grid and plate will reach a state of equilibrium instantaneously and remain as long as the current through R_{fb} is constant. With the linear input voltage, the discharge current of C_1 will remain constant through R_{fb} until the input reverses its direction.

Since the plate is the source of the output, let us take another look at its action. Remember that the output is only the a-c component of the plate voltage. When the input signal started downward, the plate voltage shot up and leveled off instantaneously and remained at this level until the input signal reversed its direction. This produced a square-wave output that is opposite in polarity to the input. The other half cycle will produce a similar output. Therefore, the output is a voltage waveform indicative of the rate of change of the input voltage. In the fire control computer, this input voltage may represent an input variable such as range and the output voltage may represent range rate or velocity.

ELECTROMECHANICAL DIFFERENTIATION.—When the derivative of a voltage is desired, a generator driven by a servomechanism may be used. In this case the servo transforms the voltage to be differentiated into a corresponding shaft position. A generator which is driven by the servo shaft produces an output voltage proportional to the speed of the motor. The generator voltage is a derivative of the rotor displacement with respect to time or a measure of the rate of rotor rotation. (See fig. 9–29.)

The derivative range is limited by the response of the servomechanism. A system having moving parts with appreciable inertia cannot respond to a voltage step function, where the slope is infinite.

MECHANICAL DIFFERENTIATION.—The derivative of a shaft rotation can be obtained by a mechanical ball-disk-roller

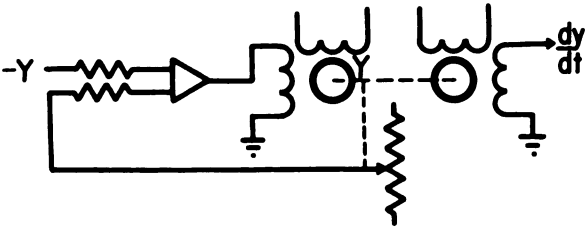


Figure 9–29.—Electromechanical differentiator.

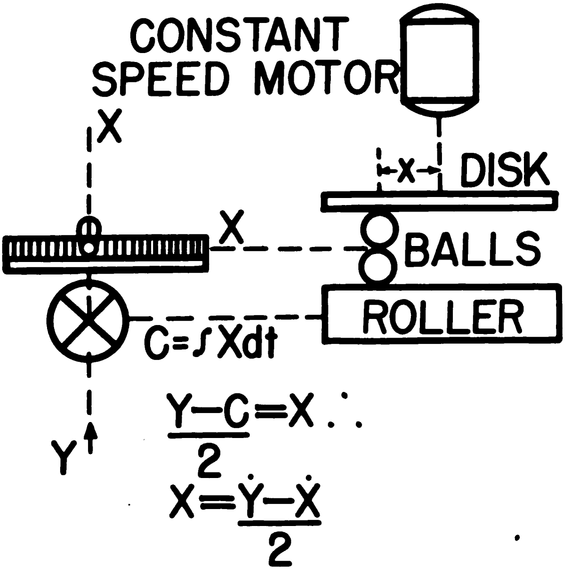


Figure 9–30.—Ball-disk-roller differentiator.

differentiator illustrated in figure 9–30. The differentiator is essentially an integrator which can be used with feedback to obtain the derivative of one quantity with respect to another. (Note: This is an implicit method of problem solving.) The device differentiates the quantity y with respect to time t and produces an output proportional to this rate.

Basically, the device consists of a flat rotating disk, driven by a motor at a constant rate; a ball and carriage assembly; and a roller. (NOTE: A detailed discussion of the operation of the basic device is covered later in this chapter under the heading "Mechanical Integrator." The inputs are *y*, a shaft rotation and *t*, which is the constant speed of disk rotation. Referring to figure 9–30, note that the input *y* is fed to a mechanical differential. The differential also is coupled to the roller. The output of the differential is a shaft rotation that is equal to one-half the difference between the two input rates. For example, if the *y* input is 50 r.p.m. and the roller is 45 r.p.m., the output would be at the rate of 2.5 r.p.m.

As in any system employing corrective feedback, the output of the differential must in some way cause the roller speed to be increased so it will be the same as the *y* input shaft. This is accomplished by having the differential output shaft drive a gear rack which is mechanically coupled to the ball and carriage assembly. Since the roller's rate of rotation should be increased to equal the *y* input, the gear rack moves the ball and carriage assembly in an outward direction sufficiently to increase the roller's speed to equal the speed of the input shaft.

The output is also taken from the gear by use of a pinion gear to drive an output shaft. The output shaft's position will be indicative of the rate of rotation of the *y* input.

Integration

As pointed out in the last chapter, integration is the process of summing up an infinite number of minute quantities. However, in the solution of the fire control problem, integration is usually the summing of certain quantities in respect to time. For example, taking the integral of velocity between certain limits of time will give the distance traveled.

The process of integration is analogous to determining the area under a curve. In the case of a step function input, it may be considered as a rectangle having one side variable with time. In figure 9–31 (A), the solid curve Y_1 shows the velocity at any time, in this case a constant velocity.

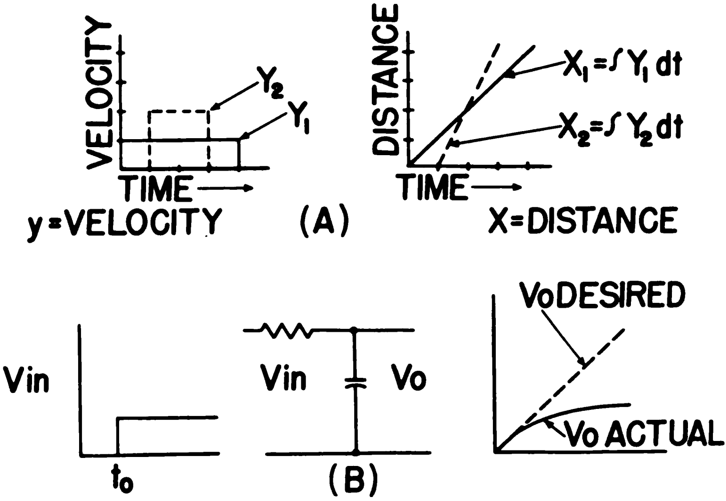


Figure 9–31.—Integration of area.

The distance traveled is equal to the velocity multiplied by the time; and with proper scale values, this distance is given by the numerical area under this (rectangular) curve; that is area = height (or velocity) multiplied by length (or time). On the distance-time diagram, the sloping line X_1 shows the total distance traveled at any instant of time; and the larger the step input the steeper the slope of the line in the distance-time diagram. Finally, lines Y_2 and X_2 represent another case.

The distance traveled, x, must continue to increase as long as there is a positive value of velocity, y. When x is represented by a voltage, there are limitations on its maximum value due to circuitry to be used.

The integral of a d-c voltage is a voltage with a constant slope as shown in figure 9–32. There is normally no need of integrating d-c voltages, but this effect is identical to the voltage wave for step inputs.

A simple integrator is shown in (A) of figure 9–33. Here a square-wave voltage is applied to the input, and the output voltage appears across the capacitor. During the positive portions of the input voltage, the output volt-

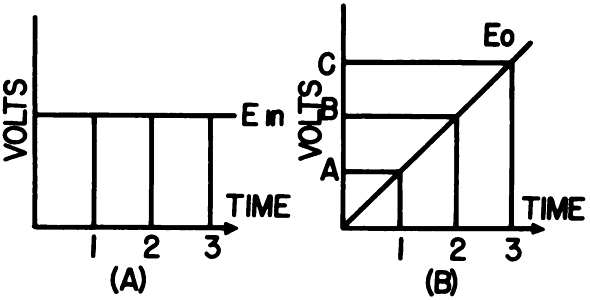


Figure 9–32.—Graphical representation of integration of a voltage.

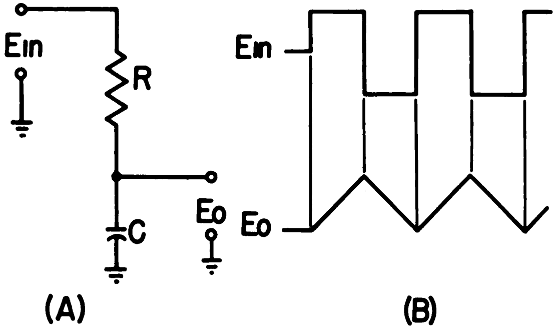


Figure 9–33.—Simple integrating circuit.

age is the sum of all the positive quantities, which result in an increasing voltage. During the negative portions of the input voltage, the output voltage is the sum of all of the negative quantities in the input, which results in a decreasing voltage. Study the waveforms in (B) of figure 9–33 and compare them with the output of the simple differentiator circuit.

An integrator circuit utilizing a feedback amplifier is shown in figure 9–34. This circuit is very similar to the differentiator amplifier circuit discussed previously. However, it should be noted that the negative feedback is coupled from plate to grid with a large coupling capacitor. This capacitor, along with its associated resistors, perform the integration. The amplifier functions only to improve its response and linearity. The input circuit also utilizes

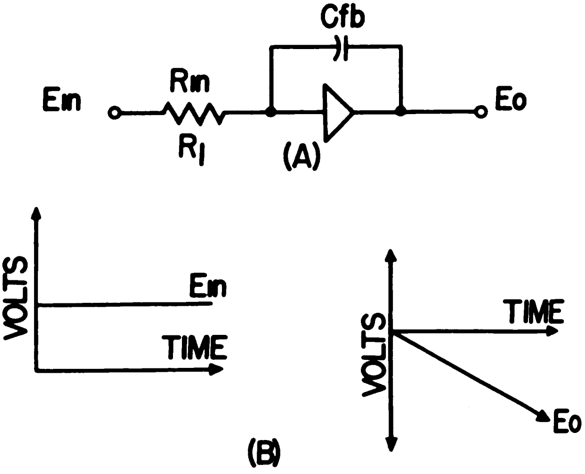


Figure 9–34.—A common integrating circuit.

an isolation resistor R_1 to allow the grid to be maintained at an almost constant potential when an input signal is applied.

The output is based on the rate of charge, or discharge, of the feedback capacitor. The amplifier functions to maintain the charge, or discharge, of the integrating capacitor in the linear portion of the RC curve. The net effect is that the capacitor voltage does not oppose the input voltage and the capacitor charging current is a direct function of the input signal voltage.

MECHANICAL INTEGRATORS.—A mechanical integrator is a mechanical device whose function is the same as the electronic integrator previously discussed. One of the most common applications of a mechanical integrator is found in a range computing system. The system computes range by computing the CHANGES OF RANGE as they occur, and adding them to the initial observed range.

Change of range for a constant range rate may be computed by multiplying the RATE at which range is changing by TIME. If this rate is constant, a simple mechanism would produce the desired output. However, range rate under

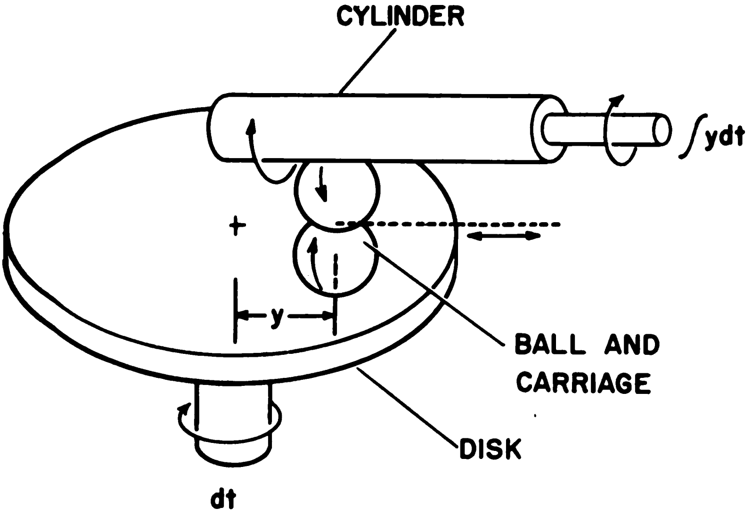


Figure 9–35.—Ball-disk-roller type integrator.

actual conditions varies over a large scale. Therefore a more complicated device must be used.

The ball-disk-roller type integrator, shown in figure 9–35, is most frequently used in aviation fire control computers. Study the diagram and note the following:

1. The disk is mounted on a gear and is turned directly by an input gear in mesh with it.
2. The two steel balls, one on top of the other, are held in position by a carriage which runs along a pair of guide rails across the face of the disk.
3. The balls turn the roller, which has an output gear at one end.
4. The balls can be positioned by the carriage anywhere along a straight line from one edge of the disk across the center to the other edge.
5. The circumference of the circle passing under the balls is greater when the balls are near the edge of the disk than when they are near the center.
6. The balls rotate faster when they are at the edge of the disk, and slower towards the center.
7. On one side of the center the balls turn in one direc-

tion, on the other side of the center in the opposite direction.

8. The pressure needed to hold the balls against one another, and against the disk and roller comes from a calibrated spring or springs.

When the target is picked up, the initial range is set into the range system. At that moment, the time motor is turned on, setting the disk in motion. The rotating disk, then, can be compared to a clock which is constantly ticking away the passage of time from the instant the target is first sighted up to each new range reading. In the range problem the disk always rotates in the same direction at a constant speed. This is a mechanical way of saying that time, which the disk represents, always goes by and never backs up.

Range rate is fed from the range rate system into the carriage input gear, which positions the carriage and the balls according to this rate. If the range rate is fast, the carriage will locate the ball away from the center near one edge of the disk. If the rate is slow, it will locate them near the center of the disk. The speed of the balls depends on their distance from the center of the plate so the speed of the balls is always proportional to the range rate.

The output roller is constantly being turned by the balls with the roller's speed determined by the speed of the balls. The position of the roller at any moment, that is the number of revolutions it has made from its initial position, tells the actual change in range during the time the disk has been turning. The output roller is geared to the range dial through a differential, so that this change in range is constantly being added to the initial setting to give present range at any moment.

Under normal operating conditions, range rate is a negative quantity since range is normally decreasing. However, the integrator is capable of determining range when both negative and positive values of range rates are supplied. A positive value of range rate would place the ball carriage on the opposite side of center of the disk causing the roller to reverse its direction of rotation.

GROUPED OPERATIONS

Thus far in this chapter computing devices for performing various mathematical operations have been discussed individually. At this point we shall consider grouping several of the instruments or devices together for the solution of a problem. It is not intended that such grouping will comprise a workable computer, but rather to show that grouping devices allows the solution of more complex equations which may be only a small portion of a complete computer. The operation of complete computers in the solution of the fire control problem will be discussed in the ensuing chapters.

Problems Encountered in Grouped Operations

When various devices are selected to carry out a grouped operation, certain problems are almost certain to develop. Such problems are present even in the grouping of the simplest devices. Here again this information is presented not to help you design a computer, but to aid you in understanding the more complex computers.

CHANGE OF REPRESENTATION.—With the connecting of two or more computing devices, the use of two or more methods of representation are frequently required. The output of the first device may not have the same representation as required by the input of the second device. An example might be the multiplication of two voltages by a potentiometer type multiplier. To successfully multiply, one of the voltages would have to be represented by a shaft rotation.

SCALE FACTOR.—Another problem that must be considered when grouping two or more devices is that of scale factor. As pointed out previously in this chapter, a change of scale factor takes place any time the device produces a proportional output. This includes devices such as adding, multiplying, dividing, etc.

IMPEDANCE MATCHING.—When the output of one electronic circuit is fed to another, the input impedance of the second circuit or stage may affect the operation of the first. Therefore, it is important that the input impedance of the second circuit be matched to the output impedance of the driving stage. A mismatch may result in an error in the computer, making the complete computer inaccurate. Two devices often used between two computing circuits are the cathode follower and impedance matching transformers. Impedance matching in the use of electrical components, such as resolvers and control transformers, must also be considered.

RELATIVE SPEED OF COMPUTATION.—The speed of response of a device is important in grouped operation. Some devices have a shorter response time than others. For example, a device with a minimum speed of computation time, when required to function longer than the minimum time, may lose a considerable percentage of its accuracy. The overall accuracy of a group of devices could be reduced below the desired tolerance due to one device requiring a longer time to function than the rest of the group. The speed of response is an important factor in regard to the stability of computers utilizing feedback.

Equation Solver

In the solution of the bombing problem, it is necessary to find the hypotenuse of a right triangle when the length of the two sides are given. Bombing computers normally utilize ground range or horizontal range because ground range rates are more constant than slant range rates. However, to minimize the possibility of error, computed ground range is converted into slant range for comparison with observed radar range. This requires a constant solution from the following equation:

$$r = \sqrt{H^2 + R^2}$$

Where r = slant range
H = altitude
R = ground range.

A block diagram of a squaring-type triangle solver is shown in figure 9–36. The quantities H and R are squared and summed. The summed quantity $(R^2 + H^2)$ is fed to

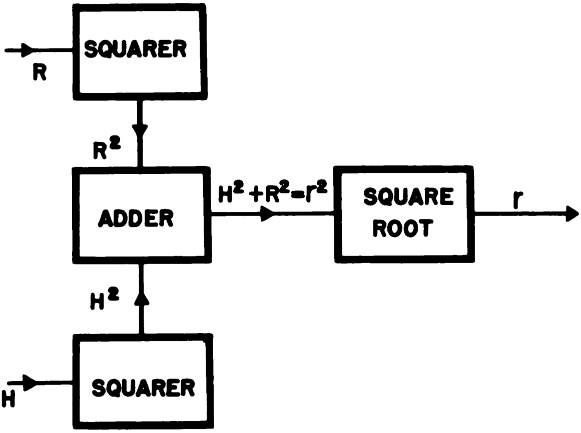


Figure 9–36.—Block diagram of right triangle solver.

a device that extracts the square root, giving an output equal to r.

A simplified circuit capable of performing the above operation is illustrated in figure 9–37. The quantities H, R, and r are represented by their respective shaft positions. Ganged potentiometers are used for squaring each quantity. A voltage proportional to $H^2 + R^2$ appears across R_4, and is fed to a feedback amplifier. Here the signal is amplified and the scale factor is corrected prior to being fed to the difference amplifier.

Potentiometers R_{15} and R_{16} are also squaring potentiometers with the output being a voltage proportional to r^2. This signal is also amplified and fed to the difference amplifier. If the voltage r^2 is equal to the voltage $H^2 + R^2$, the output from the difference amplifier is zero and the position of the r shaft is indicative of $\sqrt{H^2 + R^2}$. However, if there is a difference in the two inputs, the output signal fed to the servo amplifier will cause the servomotor to rotate in a direction to reduce the difference voltage, thus correcting the output r.

It should be remembered that this example is only one of many possible ways of solving a right triangle. It is

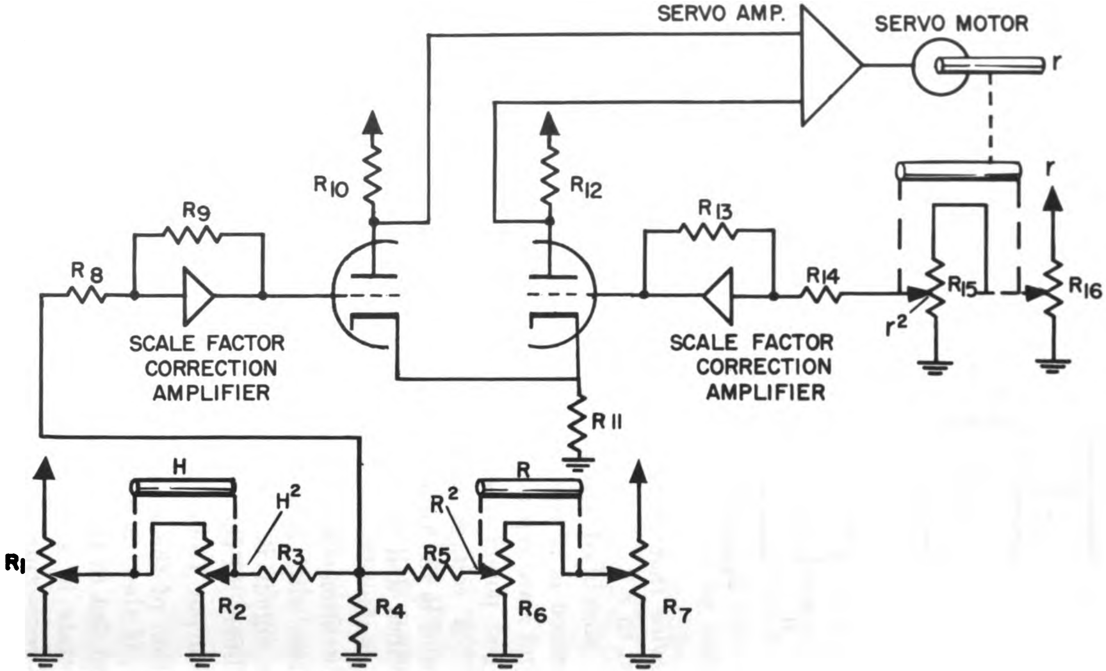


Figure 9–37.—Schematic diagram of a right triangle solver.

included only to show that the devices discussed earlier in this chapter may be grouped for the solution of more complex equations.

QUIZ

1. A linear function in mathematics is one that can be shown by a/an ____________________ line on a graph.
    a. curved
    b. straight
    c. exponential
    d. logarithmic
2. Linear functions include those functions that involve
    a. square roots, multiplication, and division
    b. squares, summation, and division
    c. summation, multiplication, and division
    d. division, multiplication, and trigonometric functions
3. While performing addition using the series circuit shown in figure 9–1,
    a. only one of the input voltages (E_1 and E_2) can be grounded
    b. both of the input voltages (E_1 and E_2) can be grounded
    c. only a-c voltages can be used
    d. only d-c voltages can be used
4. When subtracting two a-c voltages by the series circuit method,
    a. both input voltages should be grounded
    b. the inputs should be 180 degrees out of phase
    c. the phase relation has no effect on the results
    d. it is necessary to use two transformers
5. In a parallel resistive summation network the output voltage is
    a. the actual sum of the input voltages
    b. proportional to the sum of the input voltages
    c. twice the sum of the input voltages
    d. always an a-c voltage
6. In a computer the addition of physical units of an equation is made possible by the proper application of
    a. scale factors
    b. test problems
    c. digital units
    d. nonlinear functions

7. The input voltages to an electron tube difference amplifier
    a. are always positive voltages
    b. are always negative voltages
    c. are always equal in amplitude
    d. need not be from an isolated source

8. The device most commonly used for mechanical summation is the
    a. multiplier
    b. integrator
    c. bevel gear
    d. differential

9. The device most commonly used to change a mechanical input shaft rotation to an electrical signal (voltage) output is the
    a. synchro transmitter
    b. synchro receiver
    c. transformer
    d. integrator

10. The device most commonly used for electromechanical multiplication is the
    a. multiplier
    b. potentiometer
    c. differential
    d. integrator

11. Autotransformer multiplication is possible with
    a. d-c voltage only
    b. a-c or d-c voltages
    c. a-c voltage only
    d. a-c and d-c voltages

12. When using a rheostat for electromechanical division, the input voltage is applied to
    a. one end of the rheostat
    b. the movable arm of the rheostat
    c. both ends of the rheostat
    d. one end and the movable arm of the rheostat

13. In electronic division a vacuum tube is used in place of the ____________________ in a rheostat divider network.
    a. dividend
    b. quotient
    c. fixed resistor
    d. variable resistor

14. Mechanical division may be accomplished by using mechanical
    a. differentials
    b. multipliers
    c. hangers
    d. collars

15. A term may be raised to a power mechanically by using a
    a. cam
    b. differential
    c. bevel gear
    d. hanger

16. The trigonometric functions most often used in aviation fire control equipment are the
    a. secant and cosecant
    b. cosecant and cotangent
    c. sine and cosine
    d. tangent and cotangent

17. The inductive resolver has two rotor windings oriented ________ degrees from each other.
    a. 45
    b. 60
    c. 90
    d. 120

18. In the mechanical component solver illustrated in figure 9–23 the pin assembly
    a. can move in either of two directions
    b. can move in a positive direction only
    c. is not free to move
    d. can move in a negative direction only

19. The shaping network in figure 9–25 produces an output voltage that is proportional to the ______________ of the input current.
    a. square
    b. logarithm
    c. square root
    d. antilogarithm

20. The output voltage from an electronic RC differentiation network appears across
    a. the capacitor
    b. the resistor and capacitor
    c. neither the resistor nor capacitor
    d. the resistor

21. In the electronic differentiation circuit illustrated in figure 9–27, E_o is greatest when
    a. the rate of change of E_{in} is greatest
    b. the rate of change of E_{in} is zero
    c. E_{in} is greatest
    d. E_{in} is zero

22. The output from a negative feedback amplifier differentiating circuit as illustrated in figure 9–28 with a back-to-back saw-tooth input is a
    a. peaked wave
    b. square wave
    c. sine wave
    d. saw-tooth wave

23. Mechanical differentiation can be obtained by a mechanical
    a. coupling
    b. integrator
    c. worm gear
    d. bevel gear

24. The output voltage of an electronic RC integrator appears across
    a. the capacitor
    b. the resistor
    c. the resistor and capacitor
    d. neither the resistor nor capacitor

25. In an integrator circuit utilizing a feedback amplifier as illustrated in figure 9–34, the output is based on the
    a. size of R_{in}
    b. voltage drop across R_{in}
    c. size of C_{fb}
    d. rate of charge, or discharge of C_{fb}

26. In a mechanical ball-disk-roller type integrator
    a. the balls always rotate in the same direction
    b. the balls rotate faster when they are at the edge of the disk
    c. the balls rotate faster towards the center of the disk
    d. only one-half of the disk is ever used

27. The equation for solution of radar slant range (r) in the bombing problem, where H = altitude and R = ground range is
    a. $r = H^2 + R^2$
    b. $r = H^2 - R^2$
    c. $r = R^2 - H^2$
    d. $r = \sqrt{H^2 + R^2}$

CHAPTER 10

ELECTROMAGNETIC COMPUTER

The computer discussed in this chapter is not a specific computer, but contains the various elements found in a typical electromagnetic analog computer. It is designed to solve the fire control problems for guns or rockets mounted in a fixed position. It is a versatile computer in that the outputs from it may be used to control the reticule of a computing sight or the steering references of a radar indicator. However, other units are required to solve the entire fire control problem.

INTRODUCTION

When this computer is used with an optical system, its output will be fed to the gyro unit of a computing sight. The gyro unit will make the final solution for the *total* lead angle which is presented to the pilot by the optics of the sight. When the computer is used as a unit of an all-weather system, its output is fed to a two-plane rate gyro. The gyro makes the final solution for the total lead angle and transmits signals which position the steering references on a radar indicator.

It is essential that the technician have a thorough understanding of the principles of operation of the electromagnetically controlled gyroscope used with computing sights to fully understand the operation of the electromagnetic computer. Therefore, it is recommended that the technician review chapter 5 of *Aviation Fire Control Technician 3*, NavPers 10388, before continuing in this chapter. It would also be advantageous to review the section concerning the two-plane rate gyro in chapter 7 of this course.

Purpose and Characteristics

The PURPOSE of the computer is to calculate values of current which must flow through the coils of the gyro. When correct values of current flow through the range, azimuth, and elevation coils of the gyro, the desired lead angle can then be accurately generated.

The computer has several outstanding CHARACTERISTICS. Primarily, it uses potted plug-in type units, thus permitting easy replacement of components. Unlike mechanical or electron tube type computers, it utilizes phase sensitive detectors and magnetic amplifier circuits to accomplish the solution of the mathematical fire control equations. The ability of these circuits to operate without failure under conditions of extreme shock, acceleration, and temperature changes results in long periods of operation without the usual maintenance problems.

Components

The computer is composed of several different types of plug-in units, some of which are computing devices within themselves. They are:

1. Computing group.
    a. Phase balance computers (P.B.C.).
    b. Velocity computer.
    c. Computer transformer.
2. Power supply group.
    a. Power transformer.
    b. Voltage reference unit.
    c. Power supply unit.
3. Miscellaneous group.
    a. Output unit.
    b. Ballistic elements.
    c. Accelerometer.
    d. Pressure transmitter.

COMPUTING GROUP.—This group of units is discussed under "Computer Operation" later in this chapter.

Power supply group.—The power supply group, which receives its primary source of power from the aircraft's inverter, consists of the power transformer, voltage reference unit, and power supply unit. It is essential that the technician have an understanding of the purpose of this group.

The **power transformer** is a potted plug-in unit whose function is to receive the three phase, a-c output voltages from the aircraft inverter and supply to the other units of the computer voltages at various phase angles and magnitudes. It consists of two standard transformers with their primary windings energized by separate phases from the inverter. The secondary windings of the two transformers are connected in a manner that their vector sums will produce a wide range of voltages at various phase angles. (See fig. 10–1.)

The **voltage reference unit** is a potted plug-in unit whose primary function is to supply a constant d-c reference voltage to the power supply unit. This reference voltage enables the power supply to regulate the phase angle and amplitudes of the voltages required in computing circuits. The reference unit consists of a voltage doubler circuit and a voltage regulation circuit. Its input is one phase of a-c voltage from the aircraft's inverter.

The **power supply** is a partially potted unit whose function is to provide regulated power to other circuits of the computer. Composed of magnetic amplifiers and transformers, the power supply receives six a-c voltages from the **power transformer** and one d-c voltage from the **reference unit.** These inputs are used by the power supply to produce ten a-c voltages, regulated in magnitude and phase, plus one regulated d-c voltage. The a-c outputs are used by the phase sensitive detectors, and the d-c output serves as a bias voltage for the magnetic amplifiers.

Miscellaneous group.—For need of a better term, the remaining units are referred to as a miscellaneous group. However, they do perform important functions in the computer's operation.

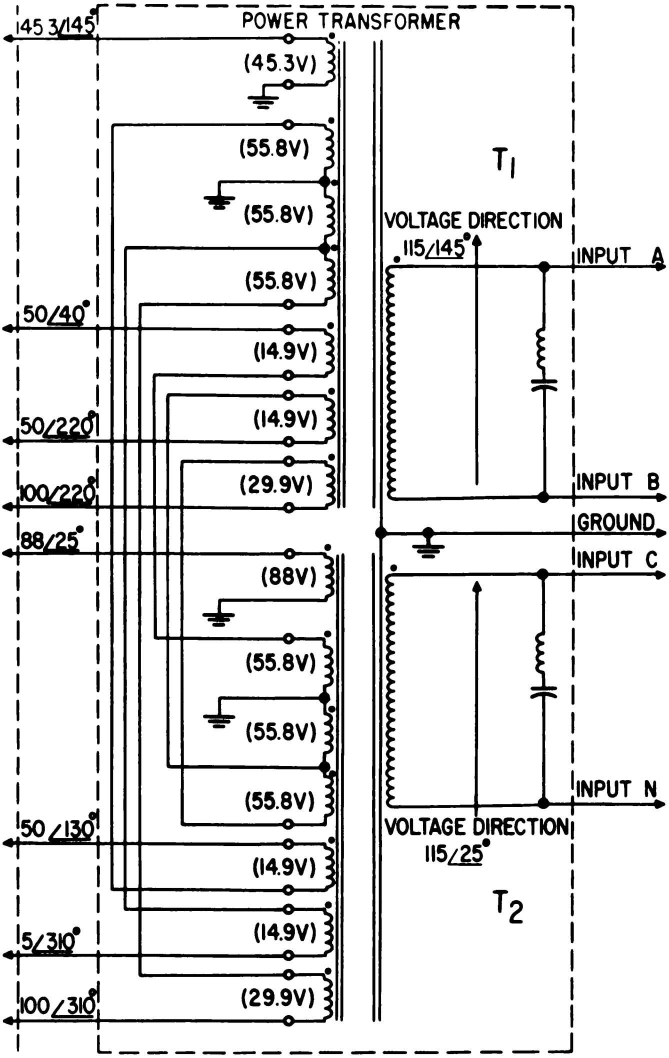


Figure 10–1.—Power transformer.

The OUTPUT UNIT is a potted plug-in unit which receives three voltages representing the solution of the fire control problem in terms of range, azimuth, and elevation. Ac-

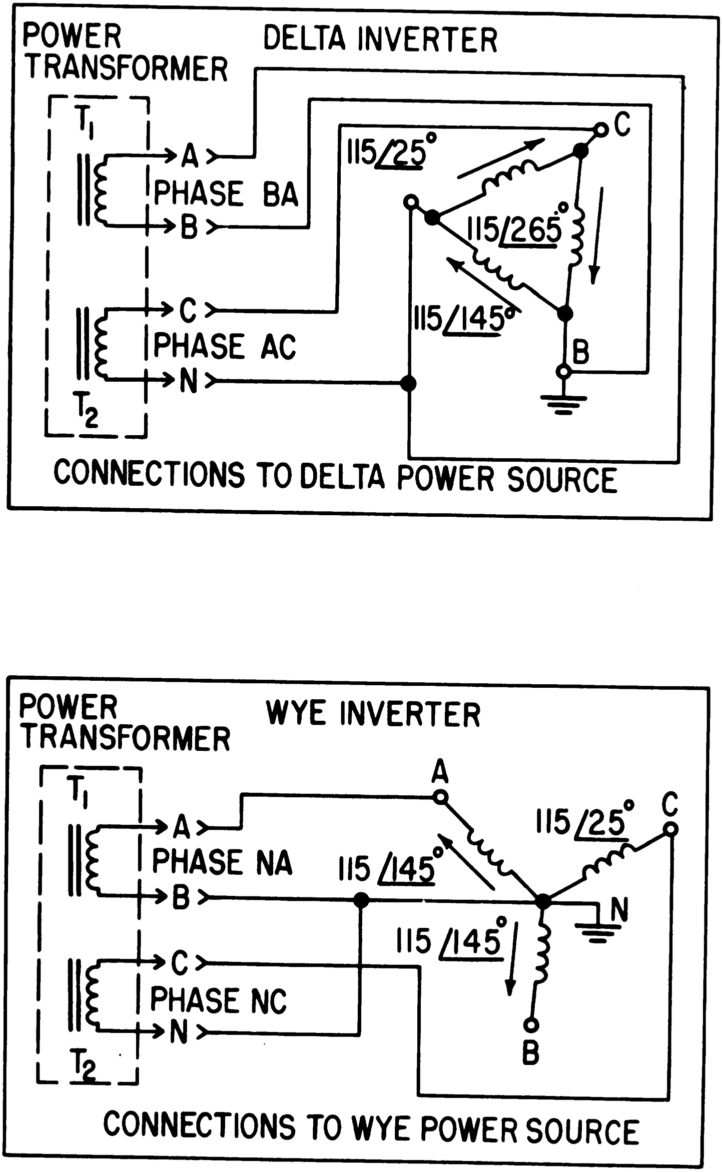


Figure 10–1.—Power transformer—Continued.

cordingly, the output unit consists of three independent circuits—range, azimuth, and elevation. The circuits are each composed of magnetic amplifiers and phase sensitive detectors with additional rectifier circuits and slope resistors as necessary.

The range circuit receives an a-c voltage E_R which is inversely proportional to time of flight (t_i) of the projectile and produces a d-c current output that is proportional to the input voltage. The d-c current flows through the range coils of the gyro, setting up the initial magnetic field in the gyro which is inversely proportional to the time of flight of the projectile.

The azimuth and elevation circuits of the output unit are essentially the same or identical. They receive a-c input voltages E_A and E_E, which are proportional to the required offsets in the horizontal and vertical planes, respectively, to compensate for the trajectory of the projectile. Tme input voltages are converted to two current values each, their difference being proportional to the input voltage in either case. Thus, these currents, as they flow through the azimuth and elevation coils, shift the magnetic center of the initial magnetic field in the gyro by amounts proportional to the offsets required.

The BALLISTIC ELEMENTS for either guns or rockets introduce factors pertaining to the characteristics of the projectile. This is done by means of transformers and resistors. Each ballistic element is designed for a specific projectile and are of the plug-in type of unit. Their inputs to the computer are of fixed value. Figure 10–2 is an example of a typical ballistic element.

The ACCELEROMETER is built in the computer. Its purpose is to detect the number of "g's" acceleration exerted on the aircraft and produce a proportional output. This information is essential in computing the amount of gravity correction required for correct lead. (A typical accelerometer was discussed in chapter 7 of this course.)

The PRESSURE TRANSMITTER is also built in the computer. Its function is to detect static air pressure and produce a

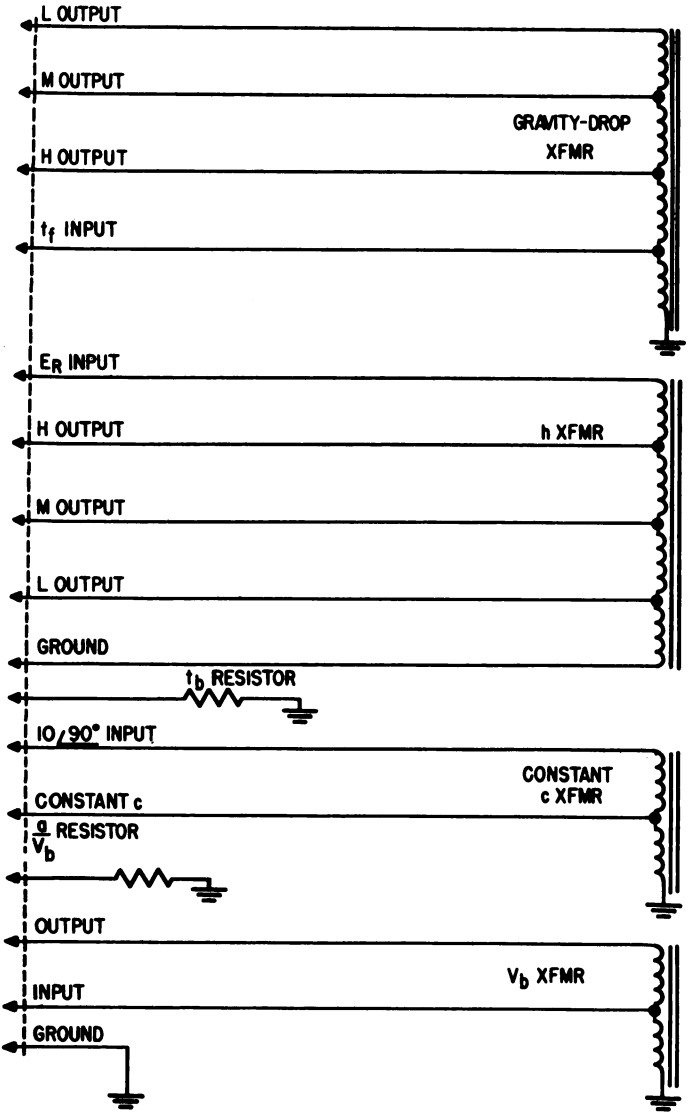


Figure 10–2.—Ballistic element.

signal proportional to it. This information is necessary because the relative density of the air is essential in computing the time of flight of a projectile. (A typical pressure sensing device was also discussed in chapter 7 of this course.)

COMPUTER PROBLEM

The computer must solve for the correct value of current for the range, azimuth, and elevation coils contained in the gyro. These values of current are based on inputs representing the factors necessary to determine the total lead angle in a fire control problem. The computer discussed in this chapter must make those computations for both gun and rocket modes of operation. However, the solutions to be discussed in this section will be based on the lead pursuit type of attack course with the weapons mounted in a fixed position.

Inputs

Some inputs received by the computer are obtained automatically from data sensing devices while others may be set in manually. (It should be recalled that various data sensing devices were discussed in detail in chapter 7 of this course.) Most of the inputs to the computer are common to both the gun and rocket modes of operation. Table 10–1 lists all the inputs to the computer.

The computer receives the inputs shown in table 10–1 and combines them in their proper relationship, thus producing the required values of current. The manner in which the input factors are combined is dictated by the mathematical equations involved in the fire control problem.

Total Lead Angle

Prior to discussing the outputs of the computer, it will be helpful to briefly analyze the total lead angle. It is composed of two primary factors, kinematic lead and ballistic lead. These factors are discussed in chapter 3 of *Aviation Fire Control Technician 3*, NavPers 10388.

Table 10–1.—Inputs to the computer.

Factors	Symbol	Source
Range	R	Radar.
Ballistics	$\dot{a}$—constant	Plug-in ballistic element.
	V_m—muzzle velocity	
Airspeed	V_A	Manual setting.
Static air pressure	P_S	Pressure transmitter.
Range rate	$\dot{R}$	Range rate computer.
Dome temperature	T_d	Sight head.
Acceleration	N	Accelerometer.
*Angle of attack	A_A	Relative wind transducer.
*Angle of skid	A_S	Relative wind transducer.
*Launcher angle	A_L	Manual setting.
*Ballistic	λo—gravity drop	Plug-in ballistic element.
	h—constant	
	t_b—burn time	
	V_b—burnt velocity	
	c—constant	

* These items are used on the rocket mode of operation only.

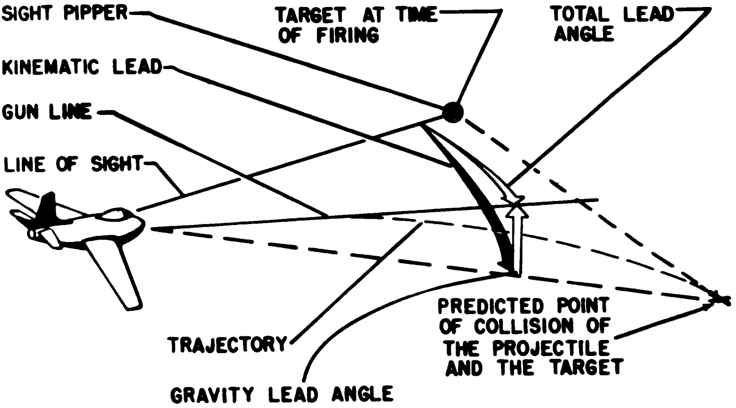


Figure 10–3.—Total lead angle.

The ballistic lead is composed of windage and gravity corrections to compensate for the projectile's trajectory. However, except in the rocket problem, gravity correction is the only part of the ballistic factor considered in the total lead angle. (See fig. 10–3.) It should be noted that all of the inputs to the computer will affect the amount of ballistic lead.

Kinematic lead is the lead required to allow for the relative motion between the target and the interceptor. The amount of kinematic lead will depend mainly on the time of flight of the projectile and the angular tracking rate.

The computer solves for the ballistic lead, which is transmitted to a gyro unit as a correction to each of the three current values. As the target is tracked by the pilot, the gyro will generate the kinematic lead. However, the gyro element of the unit is controlled by the corrective currents representing ballistic lead. Therefore, the lead angle generated by the gyro unit is the total lead angle.

Functional Block Analysis

Some of the inputs to the computer will vary throughout the attack on the target. However, the computer will maintain a continuous solution to the fire control problem in

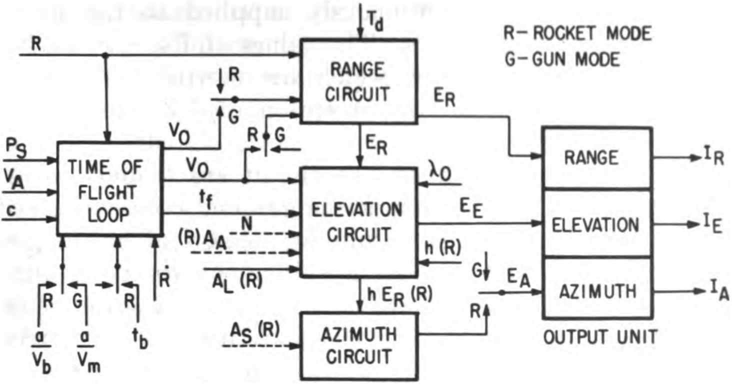


Figure 10–4.—Computer block diagram.

terms of range, azimuth, and elevation coil currents. In making its computations, several scale factors and constants will be employed.

The block diagram of the computer (fig. 10–4) will be discussed to present an overall picture of the solution of the fire control problem. The five esential blocks shown are the TIME OF FLIGHT LOOP, RANGE, ELEVATION, and AZIMUTH circuits, and the OUTPUT UNIT. Each shall be discussed with the exception of the output unit.

TIME OF FLIGHT LOOP.—The solution of the fire control problem is based on the time of flight of the projectile t_f, which is proportional to the range of the target. The amount of the total lead angle will vary with t_f; that is, the longer t_f, the larger the total lead. Therefore, kinematic lead and ballistic lead will also vary with t_f. It may be observed from figure 10–4 that the outputs from the time of flight loop are instrumental in producing the range, elevation, and azimuth coil currents.

The time of flight of the projectile is based on several variables, some of which are interdependent. Thus, the computer utilizes a time of flight loop which is capable of simultaneous solution of interdependent variables. Although there are several other inputs, the major factor in determining t_f is range R. The quantities R, P_S, and $\dot{R}$

are variable inputs continuously supplied to the circuit from data sensing devices. The values of V_A, c, a, V_b, V_m, and t_b are fixed quantities which are inserted by means of ballistic elements with the exception of V_A, which is set in manually by means of a switch.

The major outputs from the circuit are t_f and average projectile velocity V_o for both the gun and rocket modes of operation. However, it should be noted that in the gun mode of operation there are two different outputs from the circuit for V_o. The difference is a matter of scale factor. The technician should bear in mind that a definite relationship exists between V_o and t_f. For example:

$$R = V_o \cdot t_f$$

The equation may be transposed to different forms as follows:

$$\frac{R}{V_o} = t_f$$

$$\frac{R}{t_f} = V_o$$

$$\frac{1}{t_f} = \frac{V_o}{R}$$

Range circuit.—The purpose of the range circuit is to produce a gyro range coil current that is inversely proportional to the time of flight of the projectile. Although t_f is DIRECTLY PROPORTIONAL to the range of the target, the characteristics of the gyro require that a current INVERSELY PROPORTIONAL to t_f be supplied its range coil for it to generate the correct lead angle.

The range circuit receives three inputs in either mode of operation which are R, V_o, and T_d. In a previous paragraph it was established that:

$$\frac{R}{V_o} = t_f, \text{ or}$$

$$\frac{1}{t_f} = \frac{V_o}{R}$$

However, this quantity is multiplied by T_d which is a correction factor that is introduced to correct for the change of resistance of the various elements in the gyro unit due to temperature. The output of the range circuit is a voltage E_R proportional to $1/t_f$ (corrected) which is converted to a current value by the output unit. It may be noted from figure 10–4 that the output E_R is also transmitted to the elevation circuit.

ELEVATION AND AZIMUTH CIRCUITS.—The purpose of the elevation and azimuth is to produce elevation and azimuth coil currents which are proportional to the amount of correction necessary to compensate for the trajectory of the projectile in the vertical and horizontal planes, respectively. It should be noted that the azimuth circuit will be energized only in the rocket mode of operation.

The inputs to the ELEVATION circuit are E_R, V_o, t_f, N, and λ_o for both modes of operation. However, for the rocket mode additional inputs are required. They are A_A, A_L, and h. Even though each quantity appears only once as an input in figure 10–4, some may be used several times in the actual computations made by the circuit. The output of the elevation circuit is a voltage proportional to the gravity correction plus a 27½ mil elevation sight-offset. (NOTE: The elevation sight-offset is to permit greater downward lead angles.) However, in the rocket mode of operation the additional quantities stated above must also be included. The output voltage E_E is then converted to a proportional amount of current by the output unit.

The AZIMUTH circuit, used only in the rocket mode of operation, produces an output E_A from two inputs and is proportional to the amount of correction necessary to compensate for the skid angle of the aircraft during rocket fire. The output E_A is also converted to a proportional amount of current by the output unit.

COMPUTER OPERATION

The electromagnetic computer discussed in this chapter is built mainly around an ingenious circuit called a PHASE BALANCE COMPUTER. As will be shown later in this chapter, this circuit is capable of performing the following mathematical operations:

1. Multiplication.
2. Division.
3. Squaring.
4. Extraction of a square root.

Phase Balance Computer

The phase balance computer utilizes phase sensitive detectors, magnetic amplifiers, summing networks, and filter circuits. However, the phase sensitive detector only will be discussed in this chapter since the other circuits have been discussed either in this course or in *Basic Electronics*, NavPers 10087.

THE PHASE SENSITIVE DETECTOR.—The phase sensitive detector is an electronic circuit capable of detecting difference in phase between two input a-c voltages and producing a d-c output voltage proportional to this phase difference.

A basic phase sensitive detector is illustrated in figure 10–5. The phase relationship of the two equal secondaries of T_1 and secondary of T_2 should be noted. Where the primaries of T_1 and T_2 are energized with the same source, the voltage applied to CR_1 will be the sum of E_{A1} and E_B,

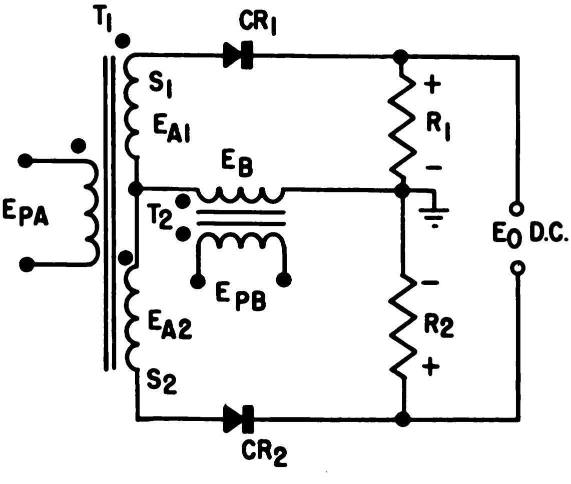


Figure 10–5.—Basic phase sensitive detector.

and the voltage applied to CR_2 will be the difference between E_{A2} and E_B.

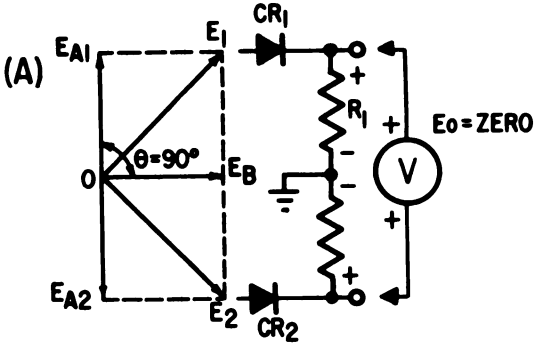
However, the phase sensitive detector does not utilize the same voltage source for both T_1 and T_2. It is constructed to provide a zero output when E_{PA} applied to T_1 and E_{PB} applied to T_2 are 90° out of phase. The operation of the circuit will be explained, utilizing vectors to show both amplitude and phase relationship of the circuit voltages.

Referring to figure 10–6 (A), the secondary voltage E_B is represented by the vector OE_B. The voltage E_{A1} is in phase with E_{PA}, which we will assume leads the voltage E_{PB} by 90°. Therefore, the vector OE_{A1} is drawn leading OE_B by 90°. (NOTE: The circuit operation is identical regardless of whether E_{A1} leads or lags E_B by 90°.) The voltage E_{A2} is 180° out of phase with E_{A1} and therefore will lag E_B by 90° as shown.

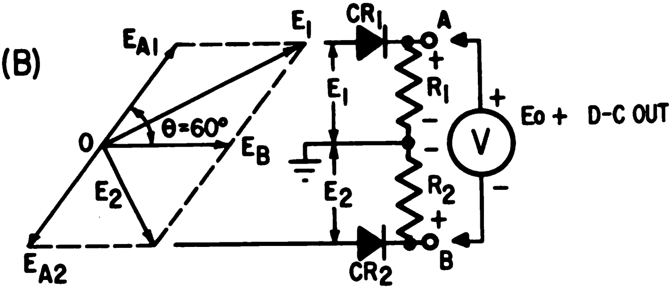
The resultant voltage of E_{A1} and E_B, represented by the vector OE_1, is developed across CR_1 and R_1, causing current to flow from ground up through R_1. Voltages E_{A2} and E_B are also combined vectorially, causing an equal current to flow through R_2. Therefore, the output voltage E_o is zero when E_{PA} and E_{PB} are 90° out of phase.

Now examine the operation of the circuit when E_{PA} leads E_{PB} by 60°. Referring to figure 10–6 (B), the vector OE_B is again drawn horizontally. However, OE_{A1} leads OE_B by only 60° as shown. The voltage E_{A2} remains 180° out of phase with E_{A1}, making OE_{A2} lag OE_B by 120°. Vectors OE_{A1} and OE_B are combined to produce OE_1–OE_B and OE_{A2} are combined to produce OE_2. By observation it should be that that vector OE_1 is somewhat longer than OE_2, thus producing a positive output voltage E_o.

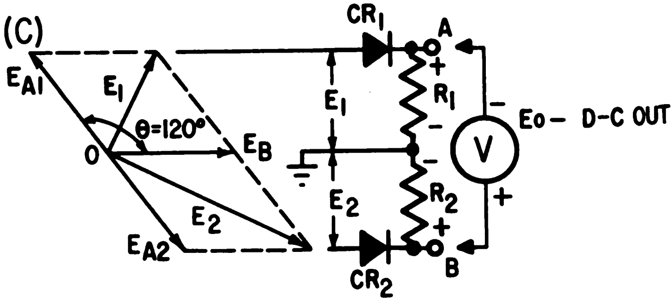
Although it was assumed that E_{PA} was leading E_{PB} by 60°, E_o will be positive for any leading angle between 0° and 90°. Figure 10–6 (C) illustrates the vectorial analysis of the operation of the circuit when E_{PA} leads E_{PB} by some angle greater than 90° but less than 180°. The output E_o s a negative voltage that is proportional to the phase angle $(\theta - 90°)$.



INPUTS 90° APART



INPUTS LESS THAN 90° APART



INPUTS MORE THAN 90° APART

Figure 10–6.—Phase detector vector diagrams.

It should be realized that the output of the half wave phase sensitive detector is a pulsating d-c voltage similar to that produced by an unfiltered half wave power supply. The output voltage may also contain harmonics of the input voltage which may cause the detector to produce erroneous data in its output.

The full wave phase sensitive detector, shown in figure 10–7, provides advantages over the basic circuit and is frequently found in operating equipment. The output of this circuit is also a pulsating d-c voltage, but its frequency is twice the input frequency, thus producing a higher d-c output voltage with a greatly reduced ripple content. The circuit also cancels the effects of all even harmonics present in the input.

A study of figure 10–7 should reveal that the full wave phase sensitive detector is merely two half wave circuits connected back-to-back with R_1 and R_2 common to both circuits. However, the secondaries of T_1 are wound in opposite directions so that current through R_1 flows through CR_1 during one half cycle and through CR_4 during the other half cycle, producing the full wave rectifier action.

The phase sensitive detector can also be used as a good

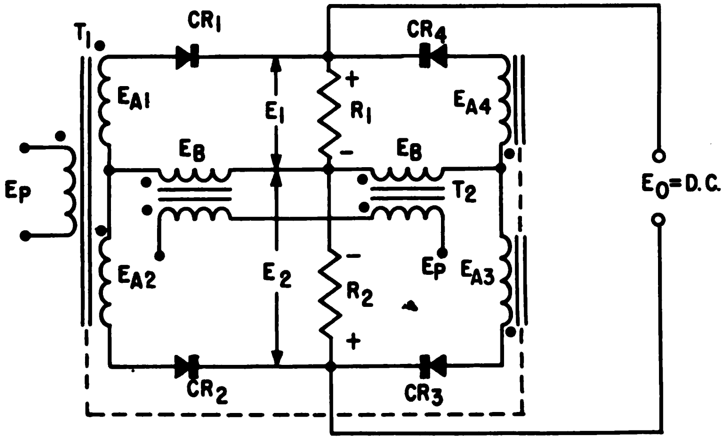


Figure 10–7.—Full wave phase sensitive detector.

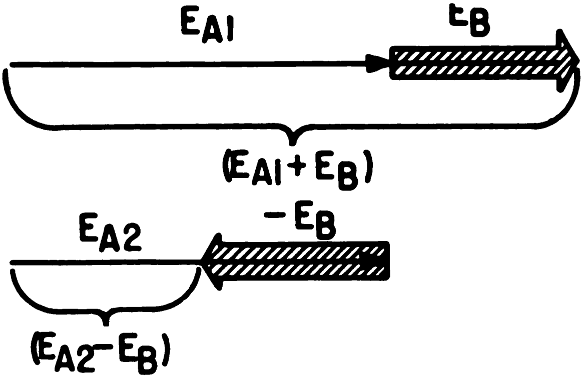


Figure 10–8.—Vector diagram of the inphase condition.

linear a-c to d-c converter. If two input voltages are in phase, no phase angle is involved and their amplitudes may be added and subtracted directly. Figure 10–8 illustrates vectorially what happens to two inphase voltages that are applied to a circuit of this type. As was pointed out previously, when the two input voltages are in phase, the output is the difference between $(E_{A1} + E_B)$ and $(E_{A2} - E_B)$. Notice that as E_B becomes larger, the output voltage will become larger. If the larger voltage is held constant, the output will be a d-c voltage which is directly proportional to the smaller of the two a-c input voltages.

ANALYSIS OF A BASIC PHASE BALANCE COMPUTER.—In the discussion thus far we have shown how a phase discriminator can produce a d-c voltage proportional to the phase difference $(\theta - 90°)$ of two a-c signals. It can also convert an a-c voltage to a d-c voltage proportional to the amplitude of the a-c signal. Like many other devices found in computers, this circuit is of little value by itself but is of the utmost importance in the overall operation of the computer.

Before going into the circuitry of the phase balance computer, we will discuss certain mathematical aspects of the computing operation for which it may be employed. The mathematical equation solved by the computer is

$$X = \frac{M_1 \times M_2}{D}$$

However, this basic equation may be utilized for the solution of the four types of mathematical problems mentioned in the beginning of this chapter.

MULTIPLICATION may be performed with this equation by holding D constant or at unity. Thus,

$$X = \frac{M_1 \times M_2}{1 \text{ (unity)}}$$

DIVISION may be performed in a similar manner by holding one of the multipliers constant (or at unity), for example M_1. Thus,

$$X = \frac{(1)\, M_2}{D}$$

SQUARING is performed by holding the divisor D at unity and applying the same quantity to both M_1 and M_2. Thus,

$$X = \frac{M_1 \cdot M_2}{(1)} = M^2$$

EXTRACTING THE SQUARE ROOT of a quantity involves a slightly more complex operation. If the quantity for which the square root is desired can be represented by a single input, this input is applied as either M_1 or M_2 with the other being held at unity. The output of the solver is then fed back as D which gives the following equation:

$$\begin{aligned} X &= \frac{M_1\,(1)}{X} \\ X^2 &= M_1\,(1) \\ X &= \sqrt{M_1\,(1)} \end{aligned}$$

If the quantity for which the square root is desired is a product of two inputs, the equation is simply

$$X = \sqrt{M_1 M_2}$$

The basic equation may be solved by inserting numerical values in the various terms as is done in similar equations in the later chapters. However, the problem may also be solved vectorially as will be shown in this chapter. (NOTE: In studying the vectorial diagram, you should cover the complete explanation before reviewing.)

Referring to figure 10–9 (A), the term M_1 is represented by the vector OA and the term M_2 is represented by the vector OA'. (Trying to understand the arrangement of the vectors as shown in figure 10–9 (A) is not necessary; however, accept the arrangement and continue the explanation.) The angle α which lies between the vectors OA' and $A'O'$ (representing the D input) is 90° and cannot be varied from this value.

Let us now refer to figure 10–9 (B) and note that the term X has been represented by the vector AC with the included angle β held at 90°. The length of X can be assumed and corrected as is done in any servo computer circuit utilizing feedback. This portion of the problem will be discussed again after other requirements have been established.

Referring to figure 10–9 (B), if a line is drawn from A' to B', it will represent the quantity $D - M_2$. This is true because the vertical component of line $A'B'$ is equal to $A'O'$ or D (in the same direction) and the horizontal component

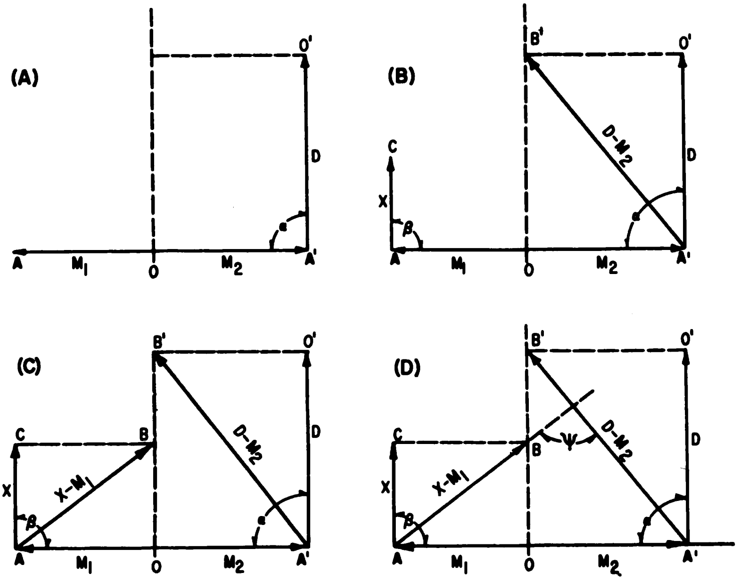


Figure 10–9.—Vectorial analysis of a P.B.C.

of $A'B'$ is equal to M_2 in length but in the opposite direction. Therefore, $A'B' = D - M_2$.

Referring now to figure 10–9 (C), a vector is drawn from A to B which represents the quantity $X - M_1$. (The vector's vertical component equals a positive X and its horizontal component equals a negative M_1.)

Referring to figure 10–9 (D), note that the vector AB is projected to cross the vector $A'B'$. This does not mean that the amplitude of $X - M_1$ is changed, but only the line is projected to allow consideration of the angle ψ. For reasons that will be brought out later, the angle ψ must be maintained at 90°. However, with the quantities M_1, M_2, and D as inputs to the computer, the amplitude of X is the only remaining means of varying the angle ψ. Thus, we vary the output X (based on inputs of M_1, M_2, and D) until the quantity X is the correct value, making ψ a right angle.

However, we must now prove that the above statement is true. We must first establish that the triangle AOB is similar to the triangle $A'OB'$. From basic mathematics we know that if two sides of a triangle are perpendicular to two sides of another triangle, the triangles are similar.

The line AB is perpendicular to $A'B'$ since ψ is maintained at 90°. Also the line $A'O'$ is perpendicular to the line AO since α is given as 90°. Therefore, the two triangles are similar.

With it proven that the triangles are similar, the following ratios may be established:

$$\frac{M_1}{D} = \frac{X}{M_2}$$

(line $OB = AC = X$ and $O'B' = OA' = M_2$)

This may be rearranged and written as follows:

$$X = \frac{M_1 M_2}{D}$$

We must now consider how this vectorial analysis is employed in the computer. A block diagram of a phase balance computer is shown in figure 10–10. The inputs are those discussed in the vectorial analysis, and the previous

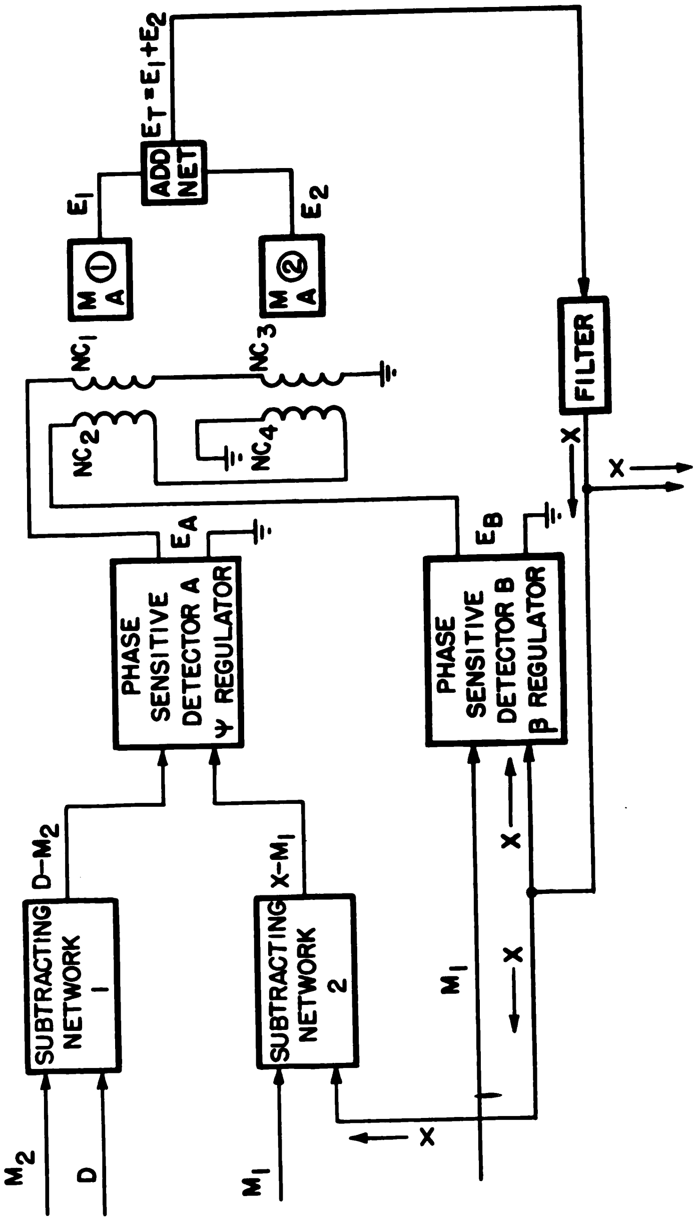


Figure 10–10.—P.B.C. block diagram.

vector diagram should be referred to frequently to insure that you are constantly aware of the phase relationship of each input and output.

The phase balance computer consists of two subtracting networks; phase sensitive detector A, which is used to regulate ψ; phase sensitive detector B, which is used to regulate β; two magnetic amplifiers; and an adding network. The arrangement of the control windings on the two magnetic amplifiers should be noted as they are of great importance in the operation of the circuit.

The first block to be discussed will be subtracting network #1. Its inputs are two a-c voltages, 90° out of phase, and the amplitudes are indicative of the quantities M_2 and D. The output of this block is an a-c voltage whose amplitude and phase is proportional to the quantity $D - M_2$.

Subtracting network #2 is a similar circuit whose inputs of M_1 and X are also represented by a-c voltages which are 90° out of phase. It should be noted that X is the output of the circuit that is fed back as an input. Anything affecting the output will also affect the input to this block. The output of this block is an a-c voltage proportional to the quantity $X - M_1$.

In the previous paragraph, it was stated that X and M_1 were 90° out of phase as represented by the angle β in figure 10–9 (B). The quantities M_1, M_2, and D are inputs whose phase angles are fixed. However, since X is developed within the computer circuit, its phase angle must be regulated. To accomplish this, the phase sensitive detector (B) is employed. Its inputs are X and M_1 as shown in the block diagram. It should be recalled that if the input voltages to this detector have an angular relation other than 90°, a d-c output voltage will be developed. The polarity of this output voltage will depend on whether the input angle is greater or less than 90°.

Suppose the angle β is such that the output voltage E_B is polarized so that current will flow down through NC_2 (thus saturating M.A.1 and increasing E_1) and up through NC_4 (thus desaturating M.A.2 and lowering E_2). Since E_1

and E_2 are not in phase, the voltage E_T, which is the vector sum of E_1 and E_2, will be changed in magnitude and in phase angle. If the magnetic amplifiers are identical so that E_1 increases by the same amount as E_2 decreases, the percent phase angle change in E_T will be much greater than the percent amplitude change. The result may be considered primarily a phase-angle change.

This change in phase angle is in such a direction that X, which is produced by filtering the harmonics from E_T, will be shifted in phase so that angle β which lies between X and M_1 will move toward 90°. Thus, phase sensitive detector (B) along with control windings NC_2 and NC_4 has become a phase regulator which holds angle β at 90°.

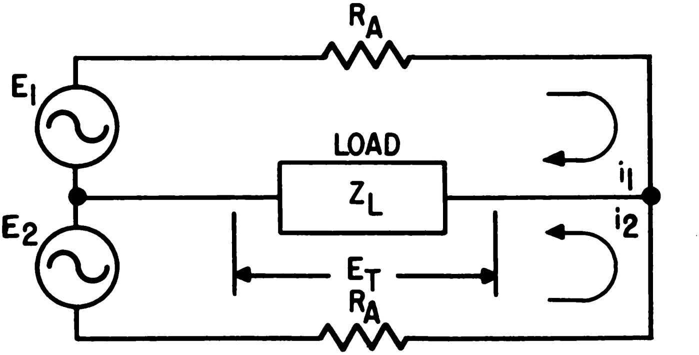
As was pointed out during the discussion of the vector analysis, the angle ψ must also be held at 90°. The only manner in which it could be varied was by varying the amplitude of X. In the phase balance computer, phase sensitive detector A and windings NC_1 and NC_3 regulate ψ by controlling the amplitude of X.

If the value of angle ψ results in the output of the phase sensitive detector (A) being polarized so that current will flow down through NC_1 and NC_3, then E_1 and E_2 will be increased. If identical magnetic amplifiers are again assumed, E_1 and E_2 will each increase by the same amount, thereby increasing the amplitude of E_T but not affecting its phase angle. The amplitude of X will therefore increase, but the phase angle of X will remain constant. The amplitude change of X will correct ψ in the desired direction for 90° regulation.

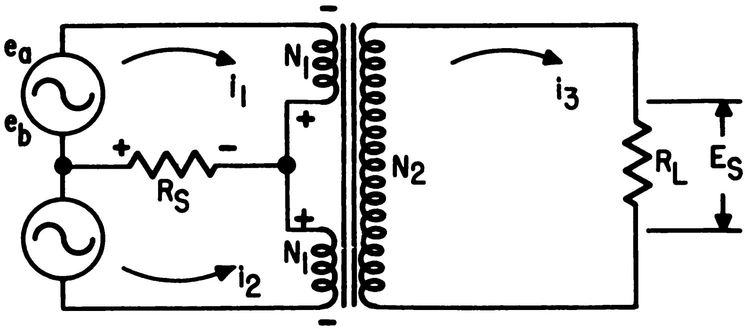
It can be seen that the combined circuitry will hold both β and ψ at 90°. Since the summation output voltage E_T of the magnetic amplifiers contains harmonics, the harmonic filter is included in the circuit. The output X will then be of good sinusoidal wave form of fundamental frequency.

All the basic circuits used in the phase balance computer have been discussed in this course with the exception of the adding and subtracting network. A simplified schematic diagram of the adding network is shown in figure 10–11 (A). The circuit inputs E_1 and E_2 are a-c voltages whose phase and amplitude may vary. The circuit will produce a voltage across the load which is proportional to the vector sum of the voltages E_1 and E_2.

The subtracting circuit, figure 10–11 (B), illustrates the subtracting networks shown in the P.B.C. block diagram. The output voltage from this circuit E_s, which is developed across the load R_L, will be the vector difference be-



(A) ADDING CIRCUIT



(B) SUBTRACTING CIRCUIT

Figure 10–11.—(A) Adding circuit; (B) subtracting circuit.

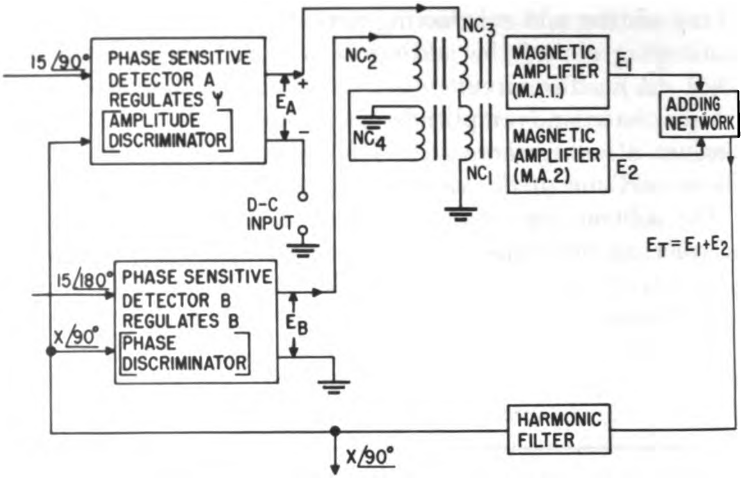


Figure 10–12.—Block diagram of the P.B.C. as an inverter.

tween the two input voltages. The swamping resistor R_s prevents interaction between the two sources.

P.B.C. USED AS AN INVERTER.—Although the phase balance computer is a basic multiplying and dividing element, it may also be used as a linear d-c to a-c inverter where the a-c output will have a phase angle of 90° with respect to the zero phase reference. Figure 10–12 illustrates a block diagram of a phase balance computer modified for use as an inverter. The circuit is identical with the circuit shown in figure 10–10 except for the absence of the subtracting networks and the types of inputs applied to the discriminators. Since the output voltage X is to be held at 90° with respect to the zero phase reference, the action of the phase discriminator is exactly the same as when the phase balance computer is a multiplier.

Velocity Computer

The velocity computer is not a special type of computing circuit, but a variation of the application of phase sensitive detectors and magnetic amplifiers. To facilitate understanding of the velocity computer, we shall first discuss its function.

The velocity computer is composed of two main sections. One section computes the velocity of a projectile as though the projectile were traveling in a vacuum (V_o'), and the other section computes the drag or decrease in velocity due to the friction of the air (ΔV_o). The two quantities are fed to another circuit where they are combined to give true average velocity of the projectile V_o.

V_o' SECTION.—The V_o' section of the velocity computer is used during the rocket mode of operation only. It is not necessary when firing guns since the velocity of the projectile would remain constant when traveling in a vacuum. Therefore, during the gun mode of operation, a constant voltage proportional to the muzzle velocity of the projectile is used in place of the output of the V_o' section.

The computation of average velocity for rockets is complicated by the fact that the rocket will continue to accelerate as long as the propellant is burning and will maintain its maximum velocity throughout the remainder of its flight. (NOTE: This is under vacuum conditions.)

We shall first consider the formula for determining average velocity of a rocket during the time the propellant is burning.

$$V_o' = \frac{0 + V_b}{2}$$

$$V_o' = \frac{V_b}{2}$$

Where

$V_b =$ velocity of the rocket at the end of burning time.

The average velocity of the rocket from the end of burn time to time of impact is equal to V_b since there are no forces, acceleration or drag, acting on it.

To utilize this information, the average velocity of the entire flight must be found which may be determined by the following formula:

$$V_o = \frac{\frac{V_b}{2} \times t_b + V_b\ (t_f - t_b)}{t_f}$$

where

V_b = velocity of the rocket at the end of burning time
t_b = burning time of the propellant
t_f = time of flight of the rocket

By simplifying, we have

$$V_o' = \frac{V_b\, t_b}{2\, t_f} + \frac{V_b\,(t_f - t_b)}{t_f}$$

V_b may be factored out and transposed as follows:

$$\frac{V_o'}{V_b} = \frac{t_b}{2\, t_f} + \left(\frac{t_f - t_b}{t_f}\right)$$

$$\frac{V_o'}{V_b} = \frac{t_b}{2\, t_f} + 1 - \frac{t_b}{t_f}$$

The right-hand terms may be combined by finding a common denominator as follows:

$$\frac{V_o'}{V_b} = \frac{t_b + 2\, t_f - 2\, t_b}{2\, t_f}$$

$$\frac{V_o'}{V_b} = \frac{2\, t_f - t_b}{2\, t_f}$$

$$\frac{V_o'}{V_b} = 1 - \frac{t_b}{2\, t_f}$$

The formula can now be utilized by the computer.

Rather than solving the above formula by mathematical manipulation, the equation is solved graphically. The V_o' computer electronically produces output voltages proportional to $\frac{V_o'}{V_b}$ for all values of t_f and t_b (within limits of the equipment).

A schematic diagram of the V_o' section of the velocity computer is shown in figure 10–13. An a-c voltage proportional of t_f is fed to a phase sensitive detector connected as a linear rectifier. Its output is a d-c voltage which is applied to the control winding of a conventional magnetic amplifier through the rocket-burning-time resistor to ground. (NOTE: The value of resistance used for the rocket-burning-time resistor will vary with the type of rocket employed.)

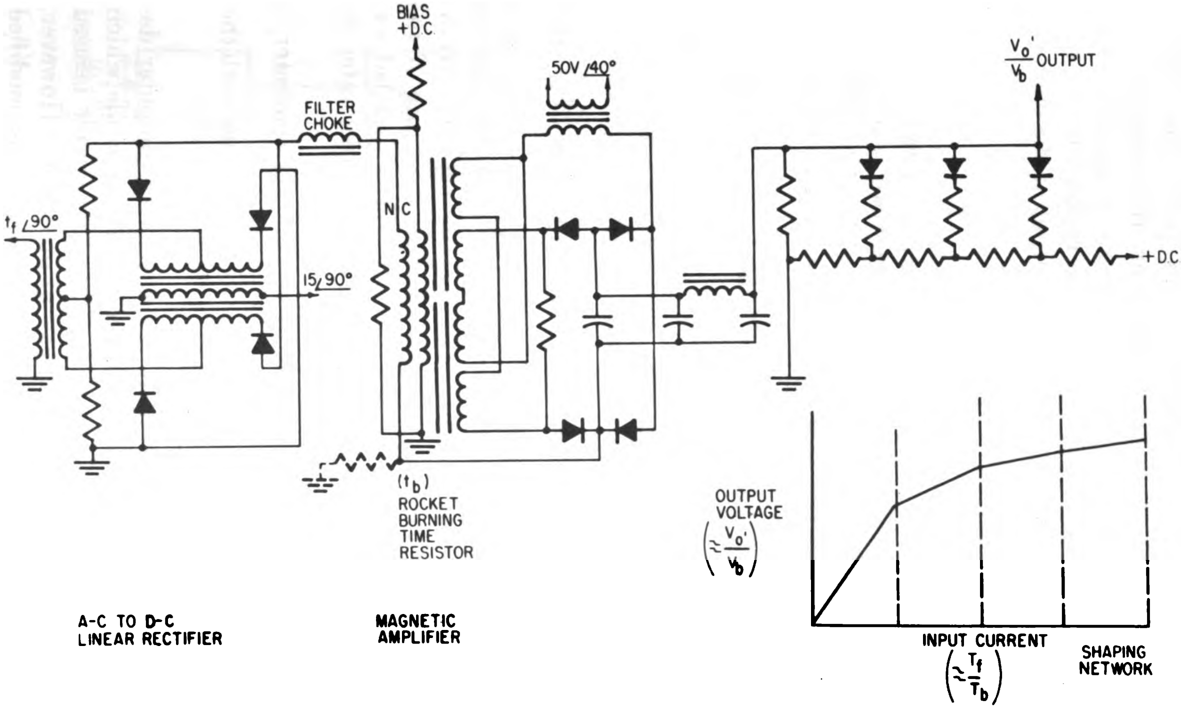

BIAS +D.C.
50V ∠40°
$\frac{V_o'}{V_b}$ OUTPUT
FILTER CHOKE
t_f ∠90°
N C
15∠90°
+D.C
(t_b) ROCKET BURNING TIME RESISTOR
OUTPUT VOLTAGE $\left(\approx \frac{V_o'}{V_b}\right)$
A-C TO D-C LINEAR RECTIFIER
MAGNETIC AMPLIFIER
INPUT CURRENT $\left(\approx \frac{T_f}{T_b}\right)$
SHAPING NETWORK

Figure 10–13.—Schematic diagram of V_o' section of velocity computer.

The output current of the magnetic amplifier is proportional to t_f since it determines (in part) the current through the control winding. However, after studying the circuit, it should be noted that the magnetic amplifier current also must flow down through the rocket-burning-time resistor. This effectively divides the output of the magnetic amplifier (t_f) by t_b or

$$I = \frac{E\ (t_f)}{R\ (t_b)}.$$

It should also be noted that the output current flowing through the rocket-burning-time resistor will tend to cancel the amplifier's amplitude of the output of t_f. This effectively reduces the amplitude of the output current but does not cut it off.

The output of the magnetic amplifier, a d-c current proportional to $\frac{t_f}{t_b}$, must return to its source; and its only path is from ground up through the shaping network. Keep in mind that the purpose of the entire circuit is to produce an output voltage proportional to $\frac{V_o'}{V_b}$ for any value of $\frac{t_f}{t_b}$ and that the ratio of the two are nonlinear. Therefore, some circuit having nonlinear characteristics must be used to produce the desired output. The shaping network accomplishes this by varying the total effective resistance of the network as the input current varies. For a detailed explanation of the operation of shaping networks refer to chapter 9 of this course.

The output of the V_o' section of the velocity computer is a d-c voltage proportional to $\frac{V_o'}{V_b}$ which is combined with the output of the $\Delta\ V_o$ section to give V_o.

$\Delta\ V_o$ SECTION.—This section of the velocity computer determines the effect of air resistance on the projectile which is combined with V_o', to supply V_o. This circuit is used during both rocket and gun modes of operation. However, as will be shown later, the circuit operation is modified when switching modes of operation.

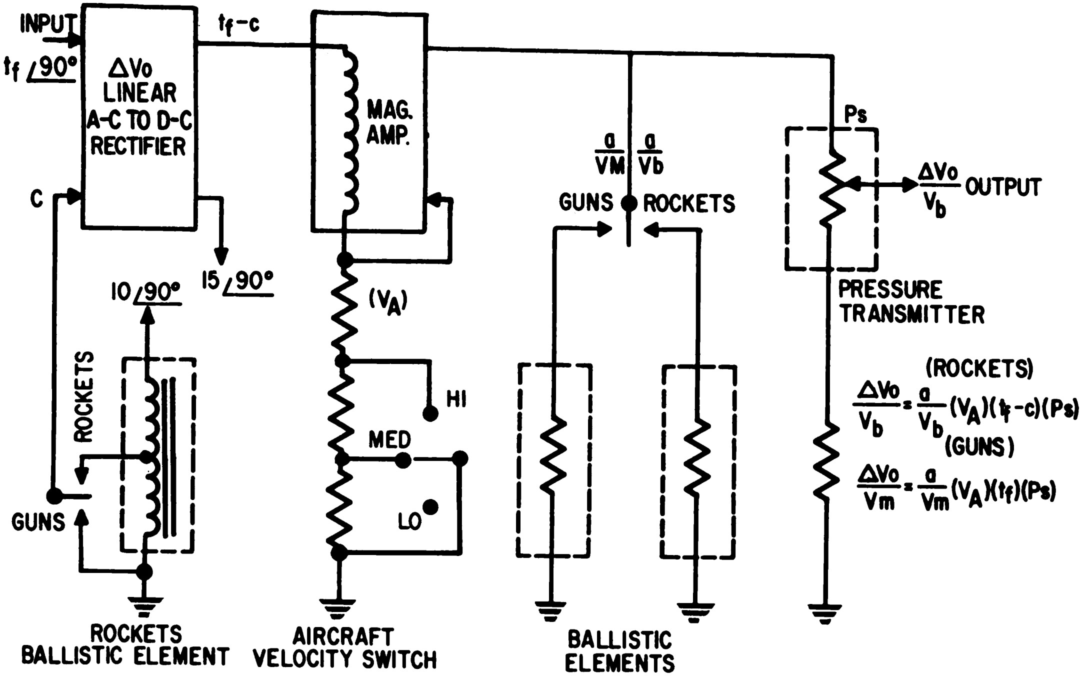


Figure 10–14.—ΔV₀ functional block diagram.

A functional diagram of the ΔV_o section is shown in figure 10–14. The formula to be solved by the computer during rocket operation is

$$\frac{\Delta V_o}{V_b} = \frac{a\, V_A\, (t_f - c)\, P_S}{V_b}$$

where

ΔV_o = drag
V_b = velocity of rocket at the end of burn time
a = constant
c = ballistic constant for the rocket
V_A = aircraft velocity
t_f = time of flight
P_S = static air pressure

The derivation of this equation is beyond the scope of this course, but it should be noted that the factors involved, except for V_b, are those which you would normally consider in determining air friction. The factor V_b is added to both sides of the equation since it is combined with $\frac{V_o}{V_b}$, thus simplifying later operations.

The operation of the circuit is similar to the V_o' computer with the exception of the shaping network. It should be noted that the output $\frac{\Delta V_o}{V_b}$ is taken from the P_S potentiometer arm. The circuit also contains two relays to permit the calculation of drag for the gun mode of operation. During this mode of operation, V_m (muzzle velocity) is used for V_b and the constant c is eliminated. Otherwise the circuit operation is the same during both modes.

The combining of the V_o' computer output and ΔV_o computer output is discussed later in this chapter under the heading "Time of Flight Loop."

Computer Transformer

The computer transformer is a plug-in unit containing several transformers connected so that they will perform several computing operations. A schematic diagram of a computer transformer is shown in figure 10–15. A typical

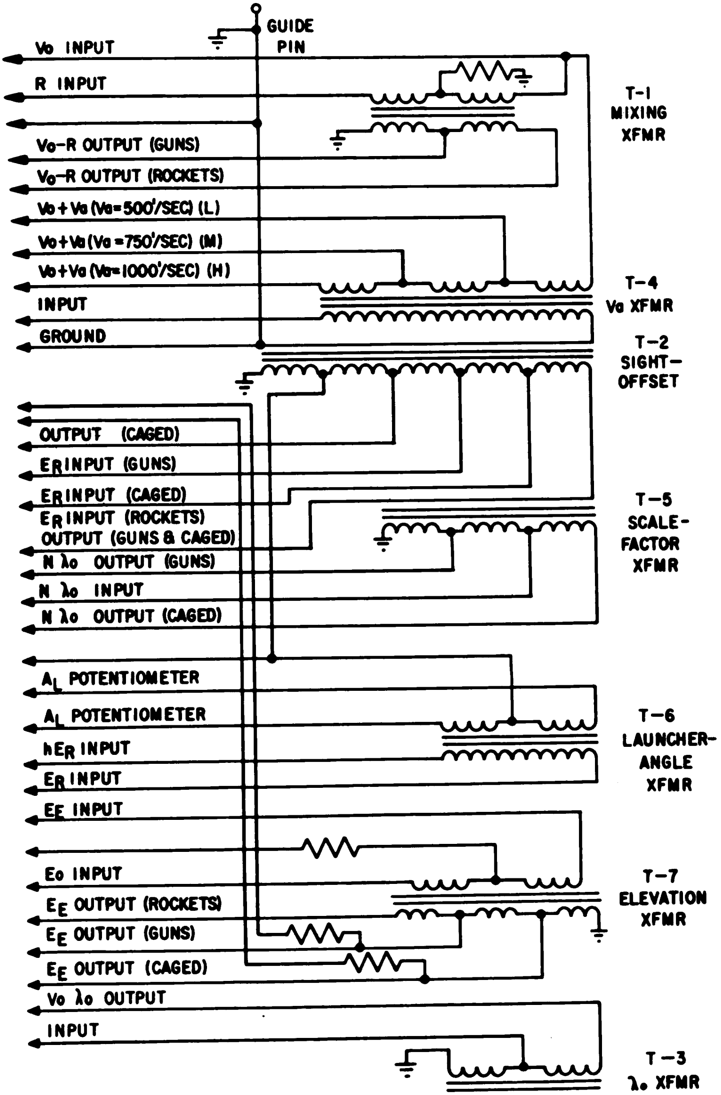


Figure 10–15.—Computer transformer.

transformer computing operation is illustrated by the mixing transformer T–1. A voltage proportional to V_o is applied to one-half of the primary winding while a voltage proportional to $-\dot{R}$ is applied to the other half. The two voltages are applied in a manner to produce an output proportional to $V_o - \dot{R}$. It should be noted that the secondary has two outputs, one for gun and one for rocket operation. With an equal number of turns in the two halves of the secondary, the voltage fed to the rocket circuits would be twice the amplitude of that used by the gun circuits. This produces no special problem since there must be a change in scale factor with the application of most computing devices.

Computing Circuits

It is assumed that the technician has a general understanding of the overall operation of the computer from the block analysis section of this chapter. Therefore, since the basic computing devices employed in the computer have been discussed, each circuit will now be discussed in detail.

TIME OF FLIGHT LOOP.—The time of flight loop is shown in block diagram form in figure 10–16 and should be referred to frequently as the discussion progresses. A d-c voltage proportional to range is applied to P.B.C. (1) used as an inverter which produces an a-c output voltage proportional to R. This quantity is fed to P.B.C. (2) connected as a divider.

At the same time a d-c voltage proportional to $\dot{R}$ is fed to P.B.C. (3) connected as an inverter. Its output, an a-c voltage, is fed to the mixing transformer T–1 which also has an input of V_o. The two inputs are applied to the primary of the mixing transformer in a manner to produce an output voltage proportional to $(V_o - \dot{R})$. This voltage is fed as a divisor to the previously mentioned divider thus producing an output of $\frac{R}{V_o - \dot{R}}$ which is proportional to t_f. Therefore for the remainder of the operation, the output of the divider will be considered t_f.

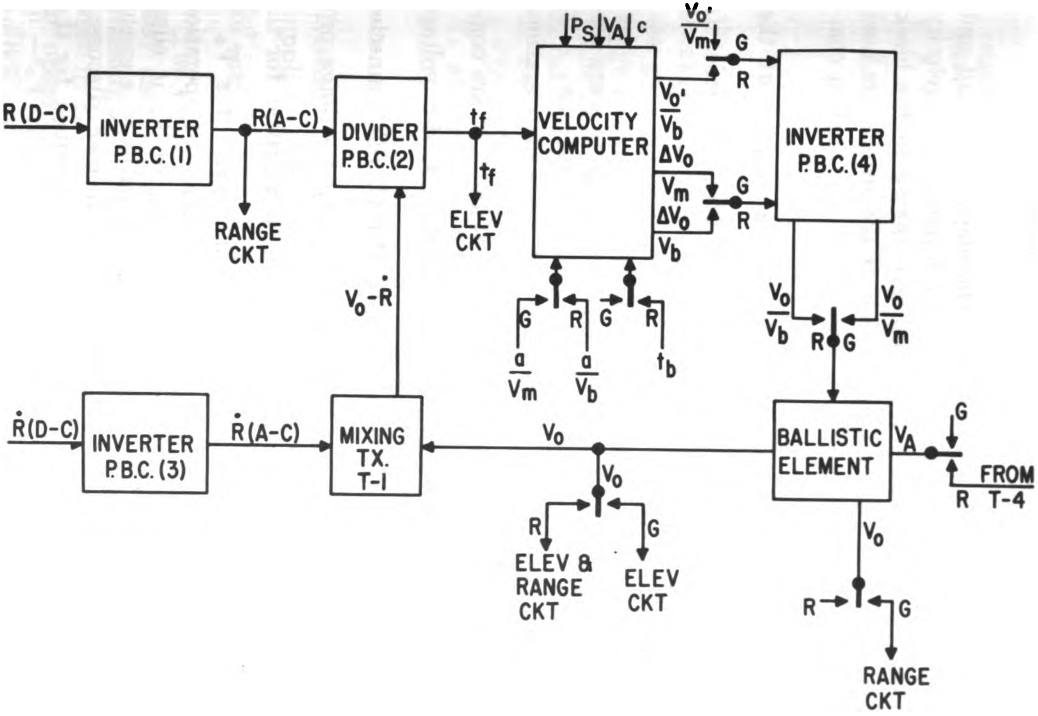


Figure 10–16.—Time of flight loop.

It should be noted at this time that t_f and V_o are interdependent. Thus, t_f must determine the value of V_o, and V_o must be used in computing the value of t_f. It should now be obvious as to why the circuit is called the time of flight loop.

The divider output t_f is fed to the elevation circuit and to the velocity computer. The other inputs to the velocity computer, as previously discussed, are shown in the block diagram. It should be noted which of the inputs are used in the gun mode of operation and which are used in computing V_o for rockets.

In the rocket mode of operation, the outputs of the velocity computer are $\frac{V_o'}{V_b}$ and $\frac{\Delta V_o}{V_b}$; in the gun mode, its output is $\frac{\Delta V_o}{V_m}$.

The equations used to solve for these outputs were discussed under "Velocity Computer" of this chapter.

When the equipment is in the rocket mode of operation, the outputs of the velocity computer $\frac{V_o'}{V_b}$ and $\frac{\Delta V_o}{V_b}$ are combined in a simple subtracting network. A d-c voltage proportional to $\frac{V_o}{V_b}$ is then fed into P.B.C. (4) connected as an inverter, thus producing an a-c output voltage proportional to $\frac{V_o}{V_b}$. This output is slightly modified for the gun mode of operation since V_m is substituted for V_b.

This output of the inverter in either mode of operation is applied to a ballistic element where V_m or V_b is eliminated, leaving V_o. One output of the ballistic element block is fed back to the mixing transformer discussed earlier. At that time a value for V_o was assumed for the purpose of establishing a voltage proportional to $V_o - \dot{R}$. This quantity is now corrected, thus correcting the output of the entire time of flight loop.

RANGE CIRCUIT.—The range coil current, developed by

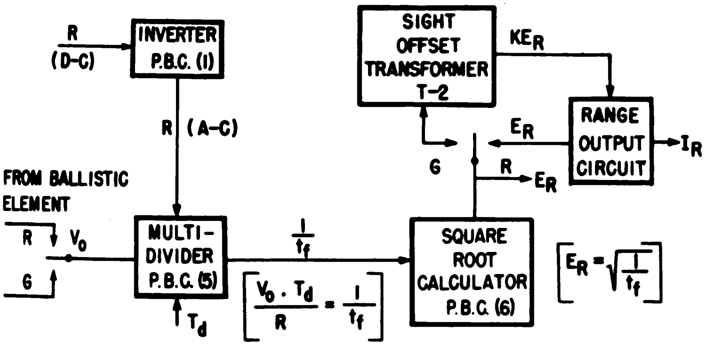


Figure 10–17.—Functional block diagram of range circuit.

the range circuit, is determined essentially by range *R*, average velocity of the projectile V_o, and temperature of the gyro dome T_d. A functional block diagram of the range circuit is shown in figure 10–17.

The first input to be discussed is *R*, a d-c voltage, which is fed to P.B.C. (1) connected as an inverter. Its output, an a-c voltage proportional to *R*, is fed to P.B.C. (5) as a "*D*" input. Also the P.B.C. has supplied V_o and T_d as M_1 and M_2 inputs. Therefore, the equation solved by P.B.C. (5) is as follows:

$$X = \frac{V_o \times T_d}{R} = \frac{1}{t_f}$$

It should now be obvious that the output of P.B.C. (5) supplied to P.B.C. (6) is connected in a manner to produce an output of E_R that is proportional to $\sqrt{\frac{1}{t_f}}$.

The output E_R is used in several parts of the elevation and azimuth circuits. Within the range circuit, E_R is transmitted directly to the range section of the output unit in the rocket mode of operation. In the gun mode of operation, E_R is transmitted to the sight-offset transformer *T*–2 where it is stepped up before going to the output unit. This is necessary since a corresponding change in range current I_R is needed to obtain a 27.5 mil sight-offset.

ELEVATION AND AZIMUTH CIRCUITS.—A functional block diagram of the elevation and azimuth circuits is shown in figure 10–18. It should be referred to frequently while following the various inputs through the circuits.

The ELEVATION portion of the circuit constitutes most of the block diagram and will be discussed first. The first input to be discussed will be t_f from the time of flight loop. In the gun mode of operation, t_f is applied to the gravity drop λ_o transformer T–3 where V_o and λ_o (a constant) are multiplied producing an output voltage proportional to the total amount of gravity drop in feet. (NOTE: This can be done because the amount of gravity drop is proportional to V_o multiplied by the gravity drop angle. The total gravity drop will also be proportional to the time of flight of the projectile. Therefore, by using appropriate scale factors, we may substitute $\lambda_o V_o$ for t_f as an input to P.B.C. (7).)

In the rocket mode, t_f is applied to the rocket ballistic element, the output of which is also $V_o\lambda_o$ for the particular V_A of the aircraft and rocket employed.

In either mode, $V_o\lambda_o$ and E_R are applied to P.B.C. (7) which is connected as a multiplier. The output of the P.B.C. is $V_o\lambda_o E_R$ as shown on the block diagram. The factor E_R was introduced to maintain the proper relation between range current and elevation current. The voltage proportional to $V_o\lambda_o E_R$ is applied to P.B.C. (8) where V_o is divided out, producting an output of $E_R\lambda_o$.

The signal $E_R\lambda_o$ is fed to an accelerometer where it is applied across the entire resistance. (NOTE: Accelerometers were discussed in chapter 7 of this course.) The wiper arm of the accelerometer is positioned by the acceleration force N (in g's) acting on the aircraft. Thus, the output from the accelerometer is $N\lambda_o E_R$ which is applied to the computer transformer during the gun mode of operation.

In the computing transformer, $N\lambda_o E_R$ is modified for scale factor by T–5 and the 27.5 mil. sight-offset by T–2. The output from the elevation section T–7 of the computing transformer is a voltage E_E which is proportional

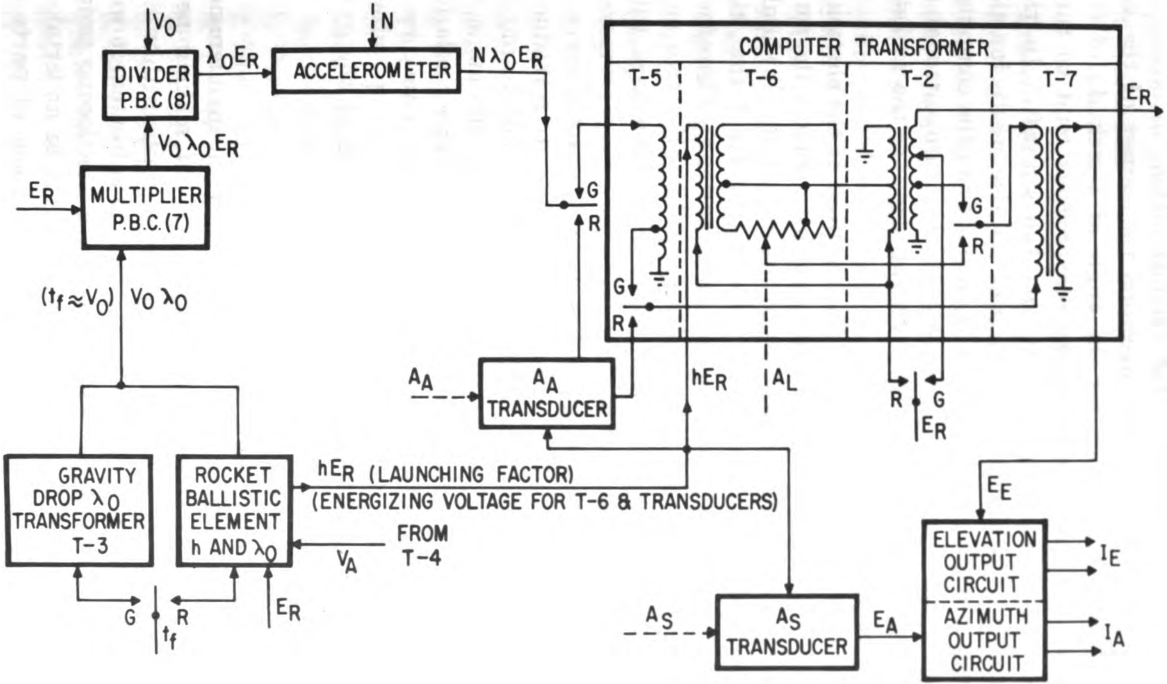


Figure 10–18.—Elevation and azimuth circuit.

to the amount of correction necessary to compensate for the bullet's trajectory in the vertical plane.

In the rocket mode of operation the output of the accelerometer is modified for the angle of attack A_A of the aircraft. This is necessary because rockets tend to turn into the direction of airflow past the aircraft. In the computer transformer, a correction is also made for the launcher angle A_L by T–6. The output from the computer transformer is also a voltage E_E which is proportional to the correction required in the vertical plane for the rocket's trajectory.

In either mode of operation E_E is applied to the elevation circuit of the output unit. This circuit controls the current through the elevation coils of the gyro unit. It should be recalled from a study of gyros in chapter 7 that the total flux of a gyro unit must be kept constant. Therefore, the elevation circuit of the output unit supplies two currents to the gyro as shown. One current increases with an increase of E_E and the other decreases by a corresponding amount. Thus, the gyro has a constant total current.

The AZIMUTH CIRCUIT is composed of the A_S transducer and the azimuth circuit of the output unit. The output of the transducer E_A is a voltage indicative of the angle of skid of the aircraft. This is the only allowance made for the trajectory of the rocket in the horizontal plane.

The voltage E_A controls the azimuth output circuit which supplies a push-pull current to azimuth coils of the gyro unit.

MAINTENANCE

Due to the circuit design and construction, maintenance on this type of computer consists mostly of making performance checks and replacing defective units within the computer. When a defective plug-in unit is located, it will be replaced with one that is known to be functioning properly. Repair of the defective unit will not be undertaken by the field activities because the replacement of parts in potted units is very impractical.

Maintenance may be classified generally into two classes —preventive and corrective. Therefore, the remainder of this discussion will be divided accordingly.

Preventive Maintenance

Preventive maintenance is performed to prolong the period of trouble-free operation of a piece of equipment. It is also an effective means of locating minor discrepancies before they develop into serious malfunctions. Most preventive maintenance work on computers requires the use of specific procedures which are carried out with the computer installed in the aircraft.

These procedures are systematically implemented by performing various types of established inspections and tests at periodic intervals.

DAILY PREFLIGHT INSPECTION.—This inspection may be referred to indiscriminately as either the preflight or daily inspection. However, it should be carried out daily prior to the use of the computer. Such a computer inspection would very likely be part of an inspection of a complete system, of which the computer is a part. The major maintenance task resulting from this inspection would be primarily that of replacing the computer, should the inspection reveal it to be defective.

This inspection is essentially a visual check of the computer. If any discrepancies are found, appropriate action should be taken to remedy them. A list of typical items to be checked during this inspection follows:

1. Proper ballistic elements.
2. Security of computer mountings.
3. Frayed cables.
4. Launcher angle setting.
5. Security of connectors.
6. Security of pitot connection.

The technician should bear in mind that the daily inspection of the SYSTEM, of which the computer is a part, may reflect a discrepancy in the computer that would not be noticeable from a visual inspection. This type of discrepancy would be a result of the operational portion of the SYSTEM's daily inspection and would in all probability necessitate the replacement of the computer.

INTERMEDIATE AND MAJOR INSPECTIONS.—Intermediate and major inspections are performed at periodic intervals based on the hours of aircraft operation. They are of the same general nature as the daily inspection except that they are more in detail. However, the degree of detail between the intermediate and major inspection will vary. Performance of these inspections will not normally require the removal of the computer from the aircraft, but will require the use of a special test set to carry out the entire inspection.

The TEST SET employed to make the complete inspection will be specifically designed for use as a portable computer test set. It will of necessity be used in the cockpit of the aircraft near the controls of the system in which the computer is a part.

Before performing any tests it will be necessary to procure and properly apply auxiliary power to the aircraft. (NOTE: This may be governed by local instructions of the activity concerned.) All other instructions for use and operation of the test set will be found in the *Handbook of Operating Instructions*. It will also contain the procedures to be followed in checking the computer and should be adhered to in detail.

The test set, however, may be capable of checking other units of a system besides the computer and it can also be used to a great advantage in the shop. Test sets normally have the necessary accessories and attachments for connecting it to the system under test.

Some of the checks with the test set will indicate a GO or NO-GO condition on a null meter. Provisions are also included for current or voltage readings. The value of these readings must of course be within specified tolerances which may be obtained from the *Handbook of Service Instructions*. (NOTE: Voltage amplitudes and phase relationships are especially critical where computing devices are concerned.)

A partial list of tests or checks to be made with the computer test set, indicating their general nature and the sequence in which they should be performed follows:

1. System input power.
2. Test set power supply output voltages.
3. Computer power supply output voltages.
4. Computer output currents and voltages (range, elevation and azimuth). If either of the last two items are not within tolerance, the computer should be replaced and taken to the shop for bench testing and repair.

Corrective Maintenance

Corrective maintenance on computers is usually performed in the shop to locate and remedy malfunctions in the computer. The necessity for this type of maintenance will usually be indicated by the results of the preventive maintenance inspections. The daily "gripe" sheet may also indicate when corrective maintenance is required. However, the preventive maintenance inspections should be performed to insure that the malfunction is in the computer before it is removed and taken to the shop.

Corrective maintenance, for discussion purposes, may be divided into two main parts—trouble isolation and replacement of units. The discussion that follows will be in respect to malfunctions that would not normally be located by visual inspection.

TROUBLE ISOLATION.—The isolation of a malfunction in a computer will require the use of a special test set and a bench test setup which will be designed for use in checking the computer and other associated units.

After the computer is removed from the aircraft and taken to the shop, several things must be done before undertaking the actual testing of the computer. A typical list of the general items might be as follows:

1. Check the power input to the bench test setup.
2. Check out of the complete bench test setup.
3. Prepare the necessary test equipment.
4. Prepare the computer to be tested.

5. Interconnect the computer to the test set and bench test setup.

The TEST SET normally used in the shop will differ from the one used on the line in performing the preventive maintenance inspections. However both may be used in the shop to an advantage. The test set designed for shop use will supply known inputs to the computer which will produce predictable outputs. The inputs are $\dot{R}$, R, P_S, N, T_d, A_A, and A_S. The output voltages from the computer are compared by means of a null meter in the test set to reference voltages which represent the correct solution to the fire control problem. If the computer is operating correctly, the computer outputs will approximately equal the reference voltages and the null meter deflections will be small. If the computer is operating incorrectly, the computer output voltages will not equal the reference voltages and the null meter deflections will be large. ***Caution:*** Care should be exercised to insure that both the computer and the test set power supplies are both connected either WYE or DELTA.

The TEST PROCEDURES to be followed in checking or testing the computer may be found in the *Handbook of Service Instructions* for the computer and should be followed at all times. Trouble isolation tables will also be found in the publication and are very helpful in remedying the malfunction, particularly for the inexperienced technician. A typical chart or table of this type is illustrated by table 10–2.

REPLACEMENT OF UNITS.—When meter indications on the test set are not within the specified tolerance for a particular test, it will usually be remedied by replacing one or more of the plug-in units. Tables or charts similar to table 10–2 should be utilized in determining which units might affect the computer's computation. The components should be replaced one at a time and in the order indicated by the chart or table. The computer should be rechecked after each unit is replaced. Correcting errors by replac-

Table 10–2.—Trouble isolation chart.

Errors encountered at test points	Units to be replaced
TP–T or TP–N (Voltage or phase or both.)	1. Power supply unit 2. Voltage reference unit 3. Power transformer unit 4. If errors persist, excessive loading on the power supply is indicated. Change computer plug-in units one at a time until the trouble is corrected.
TP–D (Voltage or phase or both.)	1. The following, one at a time: a. P.B.C. (4) b. P.B.C. (3) c. Rocket or gun ballistic element if operation differs when switching from guns to rockets. d. Velocity computer e. Computer transformer 2. P.B.C. (1) 3. P.B.C. (2)
TP–H (Voltage or phase or both.)	1. P.B.C. (8) 2. P.B.C. (7) 3. Gun ballistic element
TP–F (Voltage or phase or both.)	1. P.B.C. (5) 2. P.B.C. (6) 3. Computer transformer 4. Gun or rocket ballistic element
I_E	1. Output unit 2. Computer transformer
I_B	1. Output unit 2. Computer transformer 3. Airflow compensator
Attack and skid	1. Airflow compensator 2. Output unit

ing one of the units can very possibly correct subsequent errors that were indicated prior to the replacement.

Care should also be exercised in removing and inserting the plug-in units in an effort to prevent damage to the receptacles. The units are secured by twist-lock fasteners, some of which must be loosened from the top and others from the bottom. It is essential that all of the units be rechecked after the malfunctions have been corrected to insure that all the fasteners have been secured. After the computer has been reassembled completely, the tests should be performed again to insure correct operation of the computer before it is installed in an aircraft.

The technician should bear in mind that isolation and remedy of malfunctions are not as easy as it may seem regardless of the simplicity of changing plug-in units. The technician should become familiar with the schematic diagram and use it when attempting to isolate a trouble. It is quite possible for some malfunctions to be isolated by effective utilization of the schematic; for example, a defective relay trouble would never disappear by the replacement of plug-in units.

Plug-in units that have been removed from the computer in remedying a malfunction should not necessarily be considered defective. Each unit should be screened and carefully checked by competent personnel before they are discarded as "no good." It is quite possible that some of the so called "defective" units may function properly in another computer.

QUIZ

1. The velocity computer is composed of __________ section(s).
   a. one
   b. two
   c. three
   d. four

2. All the outputs of the velocity computer are used
   a. whenever the computer is operating
   b. during gun mode of operation
   c. during rocket mode of operation
   d. during gun and rocket mode of operation

3. The mathematical equation solved by the phase balance computer is
   a. $X = \frac{M_1 \times M_2}{D}$
   b. $X = \frac{D}{M_1 \times M_2}$
   c. $X = \frac{M_1}{D}$
   d. $XD = \frac{M_1}{M_2}$

4. The angle ψ (psi) is kept at 90 degrees by changing the
   a. phase of D
   b. amplitude of X
   c. amplitude of D
   d. phase of X

5. The total lead angle is composed of the
   a. kinematic lead angle
   b. kinematic and ballistic lead angles
   c. ballistic and elevation lead angles
   d. ballistic and azimuth lead angles

6. The purpose of the range circuit is to
   a. compute the range to the target
   b. compute the rate at which the range is changing
   c. produce a gyro range coil current proportional to target range
   d. produce a gyro range coil current inversely proportional to time of flight

7. In the gyro the magnetic center of the initial magnetic field is shifted by
   a. the range current
   b. elevation and azimuth current
   c. time of flight voltage
   d. inverse time of flight current

8. The pressure transmitter
   a. is used to pressurize the computer
   b. is a plug-in unit
   c. produces a signal inversely proportional to static pressure
   d. produces a signal proportional to static pressure

9. The computer discussed in this chapter is a/an ______________ analog computer.
   a. electrical
   b. mechanical
   c. electromagnetic
   d. electronic

10. The phase balance computer is used to
   a. perform mathematical operations
   b. calculate the phase of various voltages
   c. balance the phase of various voltages
   d. compute the solution of addition and subtraction problems

11. One of the outstanding characteristics of this computer is
   a. the difficulty encountered in replacing components
   b. the large number of vacuum tubes used
   c. its extreme sensitivity to shock, acceleration, and temperature changes
   d. its use of potted plug-in type units

12. The output unit consists of ____________ independent circuit(s).
   a. one
   b. two
   c. three
   d. four

13. The output unit receives ______________ input(s) which represent the solution to the ballistic lead problem.
    a. one
    b. two
    c. three
    d. four

14. The initial magnetic field set up in the gyro is
    a. inversely proportional to time of flight
    b. directly proportional to time of flight
    c. determined by the elevation current
    d. determined by the azimuth current

15. A full wave phase sensitive detector produces a/an
    a. pure d-c output
    b. a-c output
    c. a-c or d-c output, depending on the inputs
    d. pulsating d-c output

16. If two a-c voltages (one leading the other by 90 degrees) are applied to a phase sensitive detector, the output will be
    a. equal to the smaller input
    b. maximum positive
    c. maximum negative
    d. zero

17. Which units are located in the power supply group?
    a. Power transformer, voltage reference unit, and power supply
    b. Power supply, computer transformer, and the P.B.C.'s
    c. Power transformer, ballistic elements, and the velocity computer
    d. Output unit, voltage reference unit, and pressure transmitter

18. A phase sensitive detector requires ______________ input(s) and has ______________ output(s).
    a. 2 a-c; 1 d-c
    b. 1 d-c; 2 a-c
    c. 1 a-c; 2 d-c
    d. 2 d-c; 1 a-c

19. What do the ballistic elements furnish to the computer to alter the ballistic lead?
    a. A fixed amount of gravity drop
    b. Provide V_o (average velocity) of the projectile
    c. Factors pertaining to the characteristics of the projectile
    d. Introduce the burn time of a guns propellant

20. Kinematic lead is what portion of the total lead?
    a. Amount consisting of ballistic and gravity factors
    b. The amount of lead which is furnished to the gyro coils by means of d-c currents
    c. The amount which allows for gravity drop only
    d. Amount required to allow for relative motion between target and interceptor

21. Which two factors used in the time of flight loop are dependent upon each other and are solved for by the loop?
    a. V_o and V_A
    b. R and t_f
    c. t_f and V_o
    d. V_o and R

CHAPTER 11

ELECTROMECHANICAL COMPUTER

Electromechanical computers of the type used in aviation fire control are designed essentially to solve the fire control problems involving guns and rockets. In this respect they are similar to the electromagnetic computer discussed in chapter 10 of this course. However, this type computer may also be designed to solve the fire control problems for either fixed or flexibly mounted weapons. Other terms by which a computer of this type may be identified are armament control director or ballistics computer.

The computer to be discussed in this chapter is a typical electromechanical analog computer designed to solve for the correct lead in aiming fixed aircraft weapons. It solves the problem for either a lead collision course or a lead pursuit course.

The purpose of this computer is to supply the pilot steering information, based on computed lead, for use in making his attack on the target. The information is transmitted to an indicator in terms of four electrical signals which position a steering circle and steering dot in both elevation and azimuth. Their position, relative to each other and to the center of the indicator, provides the steering information.

The computer also has some auxiliary functions, one of which is providing an IN-RANGE signal based on when the computed time of flight of the projectile reaches a specified value. This value is determined by the type of course being flown and the weapon in use. The indication to the pilot may be a lamp that is energized by the in-range signal when the target is in firing range.

Another auxiliary function is that of providing an ANTICOLLISION warning. When the range has reduced to a minimum for safe "breakaway," an indicator lamp will be energized. The steering circle will also be deflected, indicating the direction in which to "breakaway."

The SELF-TEST feature may also be considered as an auxiliary function. By means of built-in test circuits the pilot may make inflight checks of the computer's calculations.

The outstanding characteristic of the computer is that it is essentially a systematic combination of several similar servo systems. The servo systems combine and modify the input data, thus solving for the steering error information. Another characteristic is its extensive use of potentiometers as computing instruments. However, other computing instruments are also used in the computer. Several potentiometers ganged together make it possible to use one shaft rotation to insert the analog of any quantity into several circuits simultaneously.

The computer has three modes of operation, any of which may be selected by the pilot. The three modes are: (1) lead pursuit for guns, (2) lead pursuit for rockets, or (3) lead collision for rockets.

COMPUTER PROBLEM

In order for the computer to accomplish its purpose, it must of necessity perform various complex mathematical computations. It was noted in the previous paragraph that various modes of computer operation may be utilized, further increasing its complexity. Before an understanding of the computer can be obtained, it is essential that the technician have a thorough understanding of the types of attack courses. It will also be necessary for the technician to understand the components of the total lead angle and the factors affecting each component.

Attack Courses

As discussed previously, the two main attack courses for which the computer must provide steering information are the LEAD COLLISION COURSE and the LEAD PURSUIT COURSE. The course, for which computation will be made, is determined by the pilot. It is suggested that the technician review chapter 3 of *Aviation Fire Control Technician 3*, NavPers 10388, before continuing this discussion.

LEAD COLLISION COURSE.—This type of attack course is highly impractical for the aiming of guns but is advantageous for the firing of rockets. Therefore, it will be discussed in respect to rockets only.

In the lead collision course the rocket launcher must be kept aimed at a single point in space, based on computed windage and gravity correction, at which the target is expected to be after a period of time t_f. (t_f is the time of flight in seconds of the projectile.) The primary advantage of this type of attack course is that the target can be approached at an angle outside the zone of maximum defense. Figure 11–1 illustrates a typical lead collision course problem.

Referring to figure 11–1, the target is shown to be presently at point A and the interceptor at point B. The length of the sight line is present range to the target R. The rate of closing along the range line between the target and the aircraft is $\dot{R}$. P is the antenna position angle and ω is the angular velocity of the antenna sight line due to relative motion.

To score a hit on the target at point C, it is necessary for the computer to solve for a single firing point along the lead collision course, from which the time of flight of the rocket will be equal to the time taken by the target to move to point C. A rocket fired from point B must travel to point C as the target moves from A to C. The interceptor during this time will travel from point B to point D which is a shorter distance than B to C. If the interceptor travels along the collision course after the rockets are

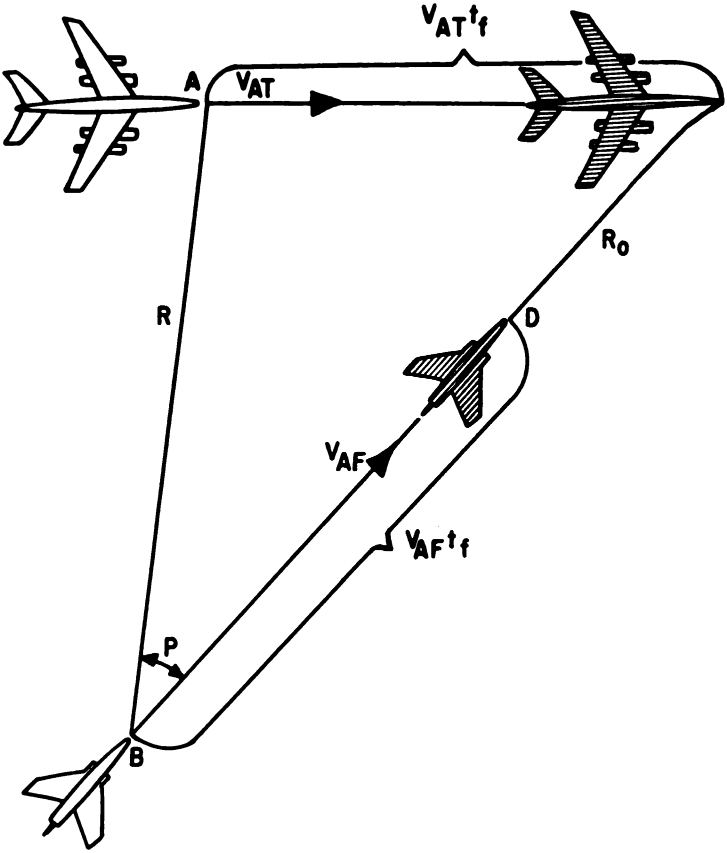


Figure 11–1.—Lead collision course.

A	Present target position.
B	Present interceptor position.
C	Future target position and projectile impact point.
D	Future interceptor position at time of impact.
R	Present range.
R_o	Preset future range.
V_{AF}	Interceptor true airspeed.
V_{AT}	Target true airspeed.
P	Antenna position angle.

launched, it will be the distance R_o from the target at the time of impact. This value is preset into the computer (referred to as minimum breakaway-range) and is the

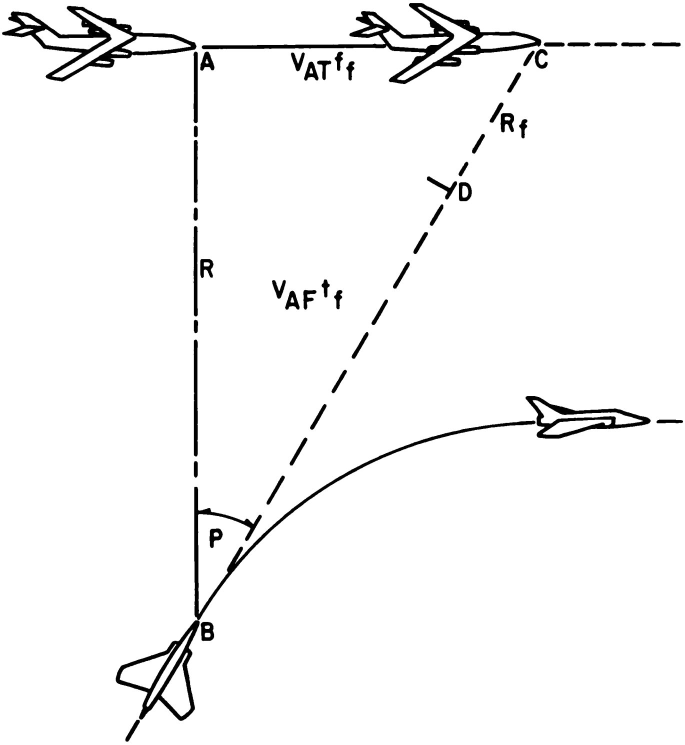


Figure 11–2.—Lead pursuit course.

A	Present target position.
B	Present interceptor position.
C	Future target position.
D	The location of interceptor when projectile strikes the target if the interceptor continued from point *B* toward point C.
R	Present range.
R_f	Future range.
V_{AF}	Interceptor true airspeed.
V_{AT}	Target true airspeed.

distance the rocket must attain AHEAD OF THE INTERCEPTOR BEFORE impact. With the preset value R_o, time of flight (t_f) of the rocket can be determined; thus, the distance that the target and interceptor each will travel during this time can be calculated by multiplying the true airspeed of each by t_f.

LEAD PURSUIT COURSE.—The pursuit course attack is equally advantageous in developing a lead angle for rockets or guns. In the pursuit course attack, the weapon is kept constantly aimed ahead of the target by the lead angle necessary to score hits on the target continuously from any point along the course that is within range. This results in a curved course as illustrated in figure 11–2. Point B is one of many instantaneous firing points along the lead pursuit course. The INSTANTANEOUS lead pursuit course is virtually identical to the lead collision course as may be observed in figure 11–2. It will be noted that R_0 is replaced by R_f, future range of the target, which must be continuously computed.

Total Lead Angles

For a computer to be effective it must develop a total lead angle regardless of the type of attack being made on the target. For purposes of this course the total lead angle will be discussed in respect to the lead pursuit course since it is equally suitable for either gun or rocket fire.

The calculated total lead angle Λ necessary to develop steering error information is composed of two primary factors—KINEMATIC LEAD Λ_k and BALLISTIC LEAD Λ_b. However, the steering error information which the pilot observes is actually the difference between computed lead angle and the actual lead angle being flown by the interceptor. Thus, as the pilot maneuvers the aircraft to bring the steering references back into proper alinement on the center of the indicator, the steering error is reduced to zero; the computed lead angle and the actual lead angle are then equal.

To effectively display the steering information on the indicator, it must be resolved into elevation and azimuth components and the total lead angle computation is made accordingly. The total lead angle Λ is equal to the vector sum of its elevation lead angle Λ_E and azimuth lead angle Λ_A. This may be written as follows:

$$\Lambda = \Lambda_E + \Lambda_A \qquad (1)$$

The elevation lead angle Λ_E is equal to the sum of the elevation factors of kinematic lead Λ_{kE} and ballistic lead Λ_{bE}, and is expressed as follows:

$$\Lambda_E = \Lambda_{kE} + \Lambda_{bE} \tag{2}$$

The azimuth lead angle Λ_A is equal to the sum of the azimuth factors of kinematic lead Λ_{kA} and ballistic lead Λ_{bA}. It may also be expressed in algebraic form as follows:

$$\Lambda_A = \Lambda_{kA} + \Lambda_{bA} \tag{3}$$

Thus, equations (1), (2), and (3) are the basic equations which the computer must solve in determining the total lead angle. The relationship of each component is illustrated in table 11–1.

Table 11–1.—Lead angle quantities.

Λ_{kA}	+	Λ_{bA}	=	Λ_A
+		+		+
Λ_{kE}	+	Λ_{bE}	=	Λ_E
Λ_k	+	Λ_b	=	Λ

Vector analysis add vertically.
Factor analysis add horizontally.

KINEMATIC LEAD ANGLE.—Kinematic lead angle is that lead angle necessary to compensate for relative motion between the target and interceptor. The factor of kinematic lead and its resolution into vectorial components will be discussed in a manner similar to that for the total lead angle. The kinematic lead Λ_k is equal to the vectorial sum of its elevation and azimuth components Λ_{kE} and Λ_{kA}, respectively. To calculate either of these two angular quantities, it is necessary to know the angular velocity of the line of sight ω_E and ω_A, present range R, time of flight of the projectile t_f, and the future range of the target R_f. The quantities R_f and t_f are not direct inputs and must be computed.

From the study of mathematics it is known that the length of an arc is equal to ωRt where ω is the angular velocity in radians per unit of time, R is the radius, and t is time. The application of this to the fire control problem is illustrated in figure 11–3. (NOTE: The angle Λ_k and

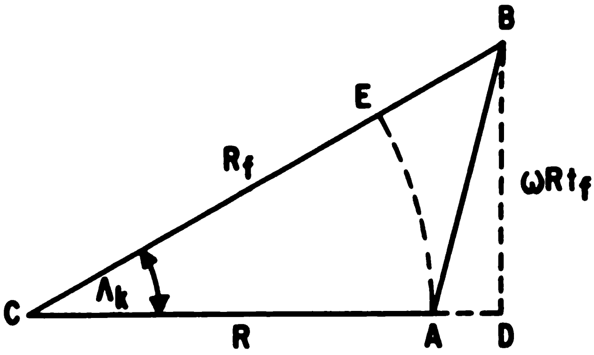


Figure 11–3.—Generation of the kinematic lead angle.

the difference in length of R_f and R are greatly exaggerated for clarity. With the small values of Λ_k employed in a normal pursuit course, the length of the arc AE may be considered equal to the length of the line BD, thus eliminating the solution of complex mathematical equations.)

For the fire control problem, the distance covered from point A for a length of time t_f, is $\omega R t_f$, as shown. If, after the time t_f, the radius (range) has increased from the value of R to the value of R_f, the sine of the angle Λ_k, which was swept through during time t_f, is equal to $\frac{\omega R t_f}{R_f}$.

Thus, the equations for the elevation and azimuth components of kinematic lead are:

$$\Lambda_{kE} = \sin^{-1} \frac{\omega_E R t_f}{R_f}$$

$$\Lambda_{kA} = \sin^{-1} \frac{\omega_A R t_f}{R_f}$$

(Note: The above equation is read as Λ_{kE} equals the angle whose sine is $\frac{\omega_E R t_f}{R_f}$.)

Ballistic lead angle.—The ballistic lead Λ_b, which is added to the kinematic lead to produce the total lead angle, compensates for the external forces acting on the projectile.

These factors are windage and gravity, Λ_{bW} and Λ_{bG}, respectively. However, the ballistics lead Λ_b must also be computed in terms of its elevation and azimuth components which are Λ_{bE} and Λ_{bA}, respectively. This is accomplished by mechanizing the ballistic tables in terms of the forces acting on the projectile.

The vertical component Λ_{bE} is the sum of the vertical factors of windage and gravity, Λ_{bWE} and Λ_{bGE}, respectively. Similarly the azimuth component Λ_{bA} is the sum of the horizontal factors Λ_{bWA} and $_{bGA}$. Thus, the basic equations solved are:

$$\Lambda_{bE} = \Lambda_{bWE} + \Lambda_{bGE}$$
$$\Lambda_{bA} = \Lambda_{bWA} + \Lambda_{bGA}$$

Table 11–2 illustrates the above equations.

Table 11–2.—Analysis of ballistic lead.

Λ_{bWE}	$+$	Λ_{bGE}	$=$	Λ_{bE}
$+$		$+$		$+$
Λ_{bWA}	$+$	Λ_{bGA}	$=$	Λ_{bA}
Λ_{bW}	$+$	Λ_{bG}	$=$	Λ_{b}

Vector analysis add vertically.
Factor analysis add horizontally.

For effective computation, each of the factors must be developed from additional equations as follows:

$$\Lambda_{bWE} = A_A \times F$$
$$\Lambda_{bGE} = -\lambda_o \cos C \cos \phi$$
$$\Lambda_{bWA} = A_S \times F$$
$$\Lambda_{bGA} = \lambda_o \cos C \sin \phi$$

Angle of attack A_A and angle of skid A_S are multiplied in either case by the factor F whose function is to produce signals proportional to the windage deflections. For the gunnery problem, F is computed as a function of static air pressure P_S, temperature T, airspeed V_A, and time of flight t_f. For rocketry, F is computed as a function of P_S, T, V_A, future range R_f, and propellant temperature T_R.

The force of gravity λ_o is in a downward direction, but

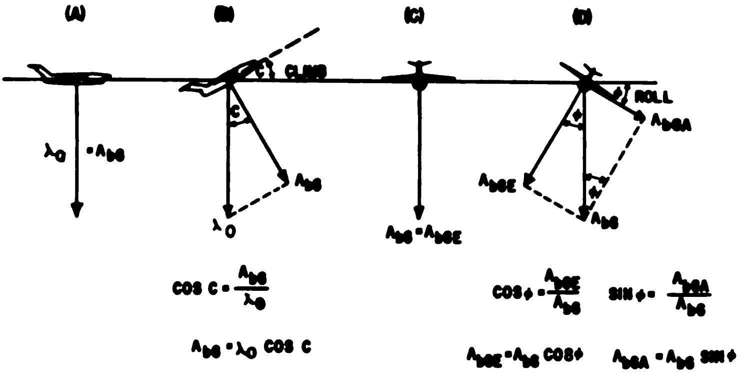

(A)
(B)
(C)
(D)
CLIMB
C
ROLL
ϕ
$\lambda_O = \Lambda_{bG}$
Λ_{bG}
λ_O
$\Lambda_{bG} = \Lambda_{bGE}$
Λ_{bGA}
Λ_{bGE}
Λ_{bG}
$\cos C = \frac{\Lambda_{bG}}{\lambda_O}$
$\Lambda_{bG} = \lambda_O \cos C$
$\cos\phi = \frac{\Lambda_{bGE}}{\Lambda_{bG}}$
$\sin\phi = \frac{\Lambda_{bGA}}{\Lambda_{bG}}$
$\Lambda_{bGE} = \Lambda_{bG} \cos\phi$
$\Lambda_{bGA} = \Lambda_{bG} \sin\phi$

Figure 11–4.—Resolution of gravity components.

since its effect on the lead angle is determined by the climb and roll attitude of the aircraft λ_o must be resolved accordingly. This is illustrated in figure 11–4.

In straight and level flight, as shown in (A) of figure 11–4, Λ_{bG} is proportional to λ_o. In part (B) of the same figure, Λ_{bg} varies with the cosine of the angle of climb C. Thus, the resulting equation is:

$$\Lambda_{bG} = \lambda_o \cos C$$

In part (C) and (D) of figure 11–4, the roll of the aircraft will further complicate the resolution of gravity. Assuming the angle of roll ϕ to be zero and a constant angle of climb, Λ_{bGE} will equal Λ_{bG} and Λ_{bGA} will be zero. However, with some angle of roll introduced, Λ_{bGA} will vary with the sine ϕ and Λ_{bGE} will vary with its cosine. Thus, the equations that result are:

$$\Lambda_{bGA} = \Lambda_{bG} \sin \phi$$
$$\Lambda_{bGE} = \Lambda_{bG} \cos \phi$$

By substituting for Λ_{bG}:

$$\Lambda_{bGA} = \lambda_o \cos C \sin \phi$$
$$\Lambda_{bGE} = \lambda_o \cos C \cos \phi$$

NOTE: $\lambda_o \cos C \cos \phi$ is a negative quantity because it is opposing the downward effect of gravity.

COMPUTER OPERATION

The basic function of the computer is to solve the equations involved in the lead collision or lead pursuit courses. The final solution is for the STEERING ERROR which, of necessity, includes the relative direction of flight of the attacking aircraft. Therefore, the computer does not necessarily solve the equations in the form as they were discussed in the previous section. It should be recalled that the steering error information is the difference between the computed lead angle and the lead angle actually being flown at any instantaneous time.

Input Data

The computer makes the solution for the steering error information from input data supplied in the form of voltage analogs. However, some of the inputs are used to compute other quantities necessary for the solution of the computer problem. For example, static air pressure, indicated temperature, and true airspeed are combined to produce air density.

The information which the computer receives is:

1. Present range ---------- R
2. Antenna (target) position P_A (azimuth)
   P_E (elevation)
3. Antenna rate ---------- ω_A (azimuth)
   ω_E (elevation)
4. True airspeed ---------- V_A
5. Static air pressure ------ P_S
6. Indicated temperature --- T
7. Gravity deflection ------ $\lambda_o \cos C \sin \phi$ (azimuth)
   $\lambda_o \cos C \cos \phi$ (elevation)
8. Angle of skid ---------- A_S
9. Angle of attack -------- A_A
10. Muzzle velocity -------- V_m
11. Rocket propellant temperature --------- T_R
12. Future range (preset)--- R_o

The sources of information are:

1. Radar.
2. Flight data unit (F.D.U.).
3. Angle of attack and skid computer.
4. Manual inputs.

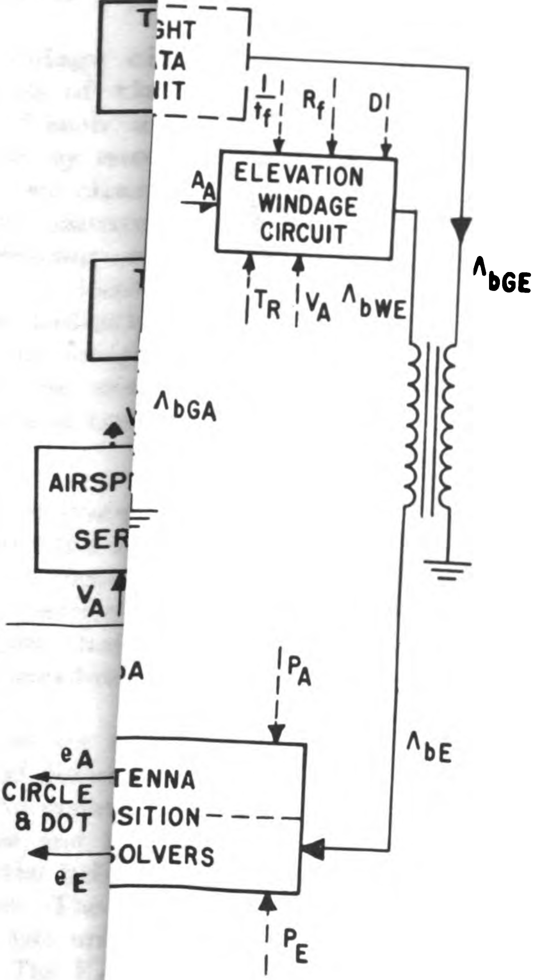
Block Analysis

For purposes of discussion the computer will be divided into three primary divisions as illustrated in figure 11–5. These divisions are the servo systems, ballistics section, and steering error section.

Most of the inputs received by the computer are mechanized by the servo systems, thus making it possible to insert the analog of a quantity into several circuits simultaneously. The analog of a quantity will be represented by the shaft position of a servomotor which may drive any number of potentiometers. This is an efficient and effective means of inserting continuously changing factors needed throughout the computer. Figure 11–5 illustrates the simultaneous insertion of various quantities into several circuits.

It is also shown in figure 11–5 that the ballistics section deals primarily with time of flight (guns or rockets), gravity deflection, and windage deflection. These circuits make the ballistic computations necessary in solving the basic equations for ballistic lead. The rocket launch time circuits are employed only during the lead collision mode of operation. These circuits introduce a time signal which is a fixed value and selected in accordance with the number of rockets in the salvo. Basically, it modifies the computed time of flight signal to be correct for the center rocket of the salvo.

It should be noted that the gravity deflection signal λ_o, as computed in the ballistics section, is transmitted to the flight data unit where it is resolved into its elevation and azimuth components. The flight data unit is not a part of the computer and will not be discussed. However, it should be recalled that the theory of resolution of the gravity



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components was discussed in the computer problem section of this chapter.

The $1/t_f$ circuit shown in figure 11–5 will be discussed in association with the $1/t_f$ servo. It receives computed t_f and serves essentially as an error detector for the $1/t_f$ servo.

The windage circuits compute the elevation and azimuth components of the windage factor for ballistic lead. The outputs of each are combined with their respective gravity component by means of a transformer. It should be noted that the two channels of the steering error section for elevation and azimuth begin with the windage circuits.

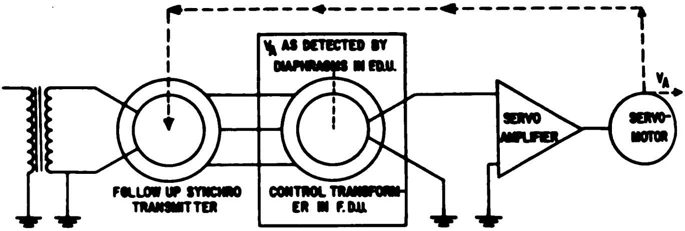
The steering error section of the computer essentially develops the kinematic lead factor and combines it with computed ballistic lead. It also determines the difference between the computed lead and the heading of the aircraft which is the steering error. This information is then amplified and transmitted to an indicator.

Servo Systems

The servo systems to be discussed do one of two things: (1) convert the input directly to a mechanical shaft position or (2) combine several inputs to produce an entirely different quantity. The new quantity will be proportional to the inputs that have been combined to produce it. This makes it possible to simplify the computing process considerably.

There are six servo systems employed by the computer and a brief discussion of each will follow. A typical computer servo system was discussed in detail in chapter 6 of this course, and it is recommended that the reader review that material before continuing further in this chapter.

V_A SERVO.—The airspeed servo receives electrical V_A from the flight data unit and converts it into a mechanical shaft position. The V_A servo is illustrated in figure 11–6. The circuit action begins with the followup synchro transmitter, the rotor of which receives its power from a transformer. The stator is connected directly to the stator of



V_A AS DETECTED BY DIAPHRAGMS IN F.D.U.
V_A
SERVO AMPLIFIER
SERVO-MOTOR
FOLLOW UP SYNCHRO TRANSMITTER
CONTROL TRANSFORMER IN F.D.U.

Figure 11–6.—Airspeed servo.

the control transformer in the F.D.U. The rotor of the control transformer is positioned by the pressure and temperature sensitive diaphragms, and a voltage proportional to V_A is induced in it. This voltage is applied to a servo amplifier, the output of which drives a servomotor. The servomotor drives the rotor of the followup synchro to a null position, thus the resulting shaft position of the servomotor is proportional to V_A.

D SERVO.—Solution of the computer problem is dependent upon the density of the air. Since all of the factors entering into the solution for air density are variable, they are combined in a servo system which provides a continuous output of correct air density.

Air density D is computed as a function of static air pressure P_S and indicated air temperature T, with compensation being made for RAM-AIR temperature rise by introducing airspeed from the V_A servo. Any change in one or more of these variables unbalances a bridge circuit, producing an error signal input to the D servo amplifier. The D SERVO FOLLOW POTENTIOMETER (rheostat-connected) forms one leg of the bridge circuit and is driven by the servomotor to rebalance the bridge and thus null the servo system. (See fig. 11–7.) The resulting shaft position of the motor is indicative of and proportional to air density D.

Referring to figure 11–7, it should be noted that V_A and T are applied in series between points a and d and P_S is applied between b and d. The potentiometer in the ac leg provides a means of balancing the bridge circuit.

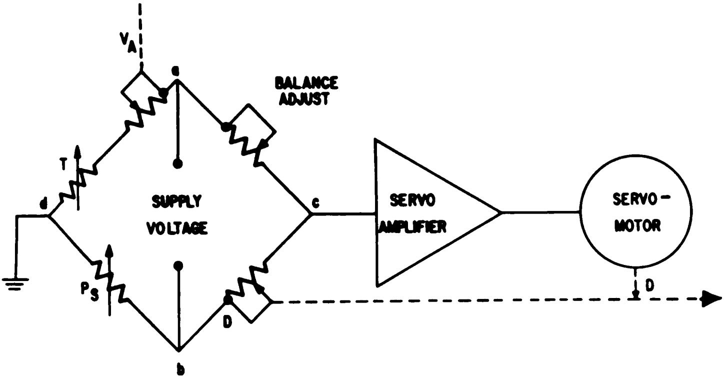
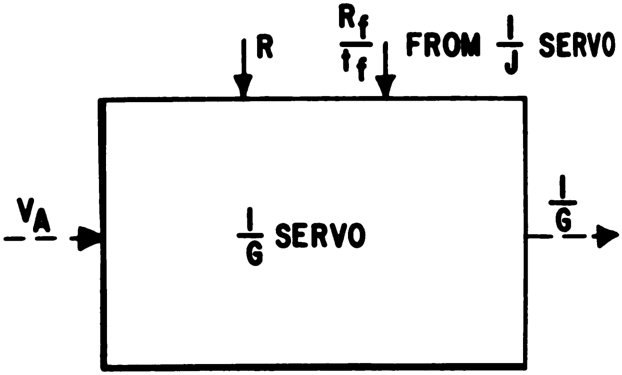


Figure 11–7.—Density servo.

1/J SERVO.—In the discussion of kinematic lead it was seen that A_k was equal to $\sin^{-1} \frac{\omega Rt_f}{R_f}$. In the design of the computer it was advantageous to let the quantity $\frac{Rt_f}{R_f}$ be represented by the term J, thus simplifying the mechanics of the computer. The term J in itself has no significant meaning other than it represents the quantity mentioned, and is referred to as the J factor. It is mechanized by a servo system, the output of which is the reciprocal of J ($1/J$). With proper scale factors incorporated the reciprocal is still proportional to the quantity that it represents.

The $1/J$ servo was discussed in chapter 6 of this course as a typical servo system. Its basic construction and operation may be observed in figure 6–5.

$1/G$ SERVO.—In the design of the computer, the final solution for the steering error employs the quantity $\frac{Rt_f}{R_f + V_A t_f}$ several times. Thus, for simplicity of computation and computer construction this quantity is represented by the term G. The term in itself has no significant meaning other than it represents this quantity as a single input wherever it is used. By using the term G, the quantity



$$G = \frac{Rt_f}{R_f + V_A t_f}$$

SERVO OUTPUT $\frac{1}{G} = \frac{R_f + V_A t_f}{Rt_f}$

SERVO EQUATION SOLVED $\frac{R}{G} - \frac{R_f}{t_f} - V_A = 0$

Figure 11–8.—1/G servo block diagram.

$\frac{Rt_f}{R_f + V_A t_f}$ can be introduced where needed by a single input rather than introducing the individual factors required separately.

The G factor is introduced as a reciprocal $1/G$ which is proportional to the G factor. The G factor is mechanized in a manner similar to that used for the J factor. The output of the $1/G$ servo is a shaft rotation proportional to G and is composed of the inputs R, R_f, t_f, and V_A. Only a block diagram of the $1/G$ servo is shown in figure 11–8 because its construction and operation is similar to the $1/J$ servo shown in figure 6–5.

$1/t_f$ SERVO.—The reciprocal time of flight servo does not compute any values or quantities but converts the quantity t_f from electrical representation to $1/t_f$ represented by a shaft position or rotation. As in the other servo systems discussed, the quantity $1/t_f$ can then be inserted into several equations simultaneously.

As shown in the $1/t_f$ servo system block diagram (fig. 11–9), the servo system receives an electrical input of t_f from the t_f computer circuits which is applied to the isolation amplifier. This amplifier acts as a buffer between the computer and servo circuits and has a gain of unity. Its output is transmitted to the t_f rectifier and also applied to the $1/t_f$ potentiometer R_1. The rectified t_f is modulated with a 10 kc. carrier which controls the gain compensator.

The output of R_1 is applied to the secondary of a t_f followup transformer which produces a signal quantity of $1-t_f/t_f$. (NOTE: The quantity one represents unity but will be considered as one for the explanation.) When this quantity is equal to zero, the $1/t_f$ servo has completely followed any error signal which has been nulled out. (NOTE: The action of the t_f followup transformer and

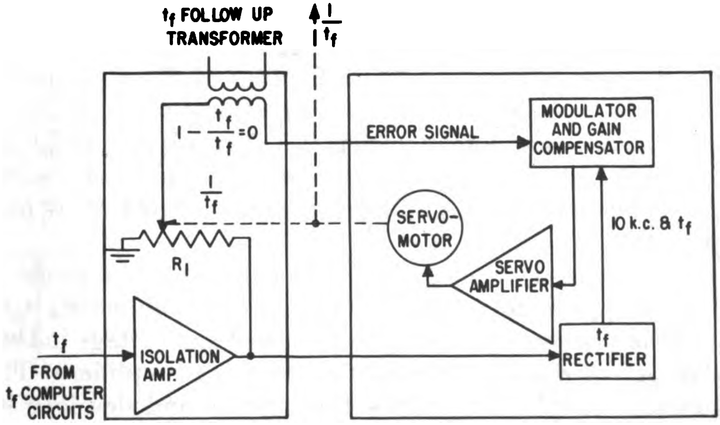


Figure 11–9.—$1/t_f$ servo block diagram.

potentiometer is identical to that of an error detector discussed in chapter 5 of this course.) When an error signal exists at the transformer from a sudden change in t_f or due to a lag in the servo system, it is applied to a summing network that also receives the 10 kc. modulated t_f signal from the t_f rectifier. The combination error signal and 10 kc. carrier are then applied to the servo amplifier by way of the gain compensator. The output of the servo amplifier then drives the servomotor which will continue to function until the error signal is canceled out by repositioning of the wiper of R_1. When nulled, the shaft of the servomotor will be indicative of the factor $1/t_f$, and all potentiometers to which it is attached will be positioned accordingly.

R_f SERVO.—Mechanization of the quantity R_f begins in the R_f demodulator as shown in figure 11–10. It receives the range error term E_R from the antenna elevation resolver. The error term E_R is a range correction factor necessary to compensate for the climb angle of the interceptor. This factor must be considered since the range of the projectile will vary with the angle at which it is fired relative to the horizontal. Therefore, the quantity E_R must be proportional to the resultant effect of the angle of climb of the interceptor and gravity. (NOTE: The angular information required in determining E_R is furnished the elevation antenna resolver by the flight data unit.)

Referring to figure 11–10, the output of the R_f demodulator is a negative d-c voltage proportional to E_R which is developed across potentiometer R_1. The wiper arm of R_1 is positioned by the servomotor which is proportional to R_f. Thus, the voltage applied to point A from R_1 is proportional to $-(R_f \cdot E_R)$.

A positive d-c voltage proportional to present range R is also applied to point A. The negative voltage $E_R \cdot R_f$ and the positive voltage R are combined and voltage indicative of their sum is fed to the summing amplifier. The summing amplifier amplifies this voltage and develops its output across the potentiometer R_2. (Note the voltage

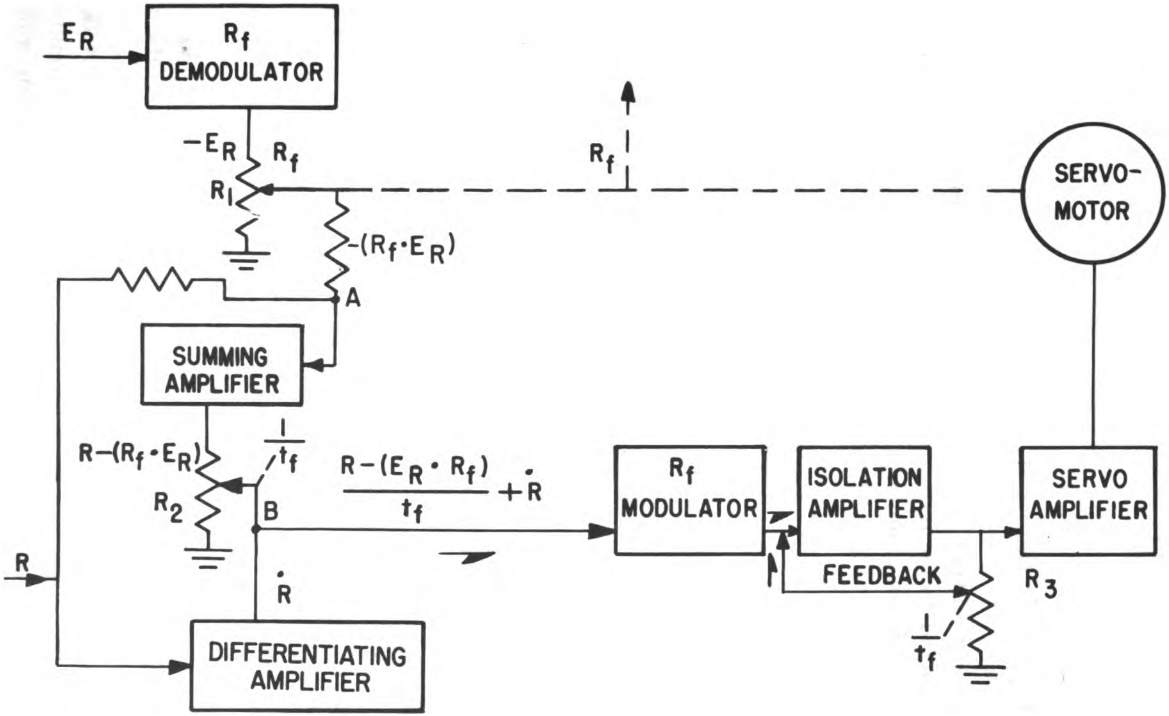


Figure 11–10.—R_f servo block diagram.

across R_2 is proportional to $R - (E_R \cdot R_f)$.) The wiper arm of R_2 is positioned by the $1/t_f$ servomotor giving the term

$$\frac{R - (E_R \cdot R_f)}{t_f}$$

Again referring to figure 11–10, it should be noted that the quantity R is fed to a differentiating amplifier. The amplifiers output is range rate (a negative quantity) which is also fed to point B where it is summed with the positive output of the summing amplifier represented in the equation above. Thus, the input to the R_f modulator is proportional to

$$\frac{R - (E_R \cdot R_f)}{t_f} + \dot{R}$$

(NOTE: Under normal conditions $\dot{R}$ is a negative quantity.)

The above equation is solved by the R_f servo system. As any servo system used for a computer, it must be designed to give a zero output when the equation is solved. Therefore, the above equation is set equal to zero.

The remainder of the servo loop consists of an isolation amplifier and its feedback circuit, a servo amplifier, and a servomotor. Their operation is similar to that discussed previously in chapter 6 of this course with the exception of the feedback loop. The amount of feedback is made proportional to the quantity $1/t_f$. This permits the necessary gain compensation required to maintain a fairly constant error signal throughout the solution of the fire control problem.

Ballistic Computation

In the discussion of the ballistic circuits in the following paragraphs it will be assumed that the servos position the shafts of the various potentiometers. Therefore, no mention will be made of how the quantities are inserted, unless by some means other than a servo. Three circuits will be discussed: (1) of flight, (2) gravity deflection, and (3) windage deflection.

TIME OF FLIGHT CIRCUIT.—Since the computer is designed to compute lead for both guns and rockets, it is essential that it contain two different time of flight circuits. Only the time of flight circuit for guns will be discussed in detail in this course since the principles of operation of each is essentially the same.

The function of the time of flight circuit, as the name implies, is to compute the time required for the projectile to reach the target after it is fired. The circuit shown in figure 11–11 calculates t_f as a function of V_m, R_f, V_A, D, and $1/t_f$. The general equation is:

$$t_f = (D \cdot R_f) + (D \cdot 1/t_f \cdot V_A) + (V_m \cdot R_f) \qquad (1)$$

The first two quantities in the equation represent lost time of flight due to air drag on the projectile, which must be taken into consideration for accurate computation of t_f. It may be observed from figure 11–11 that the t_f circuit has three main parts, and that each part is devoted to developing one of the terms in the general equation.

The computation is made by means of excitation transformers, fixed resistors, and function-wound potentiometers controlled by the mechanized variables. The first part of the circuit to be discussed will be the multiplication of D (density) and R_f (future range). The secondary S_3 of T_1 applies a 400-cycle voltage across R_6, the D potentiometer. The wiper arm of R_6 is positioned by the D servomotor making the voltage across R_7 proportional to D. The arm of R_7 is positioned by the R_f servomotor, making its output proportional to $D \times R_f$ which is the first term in the above equation.

The second term $D \cdot 1/t_f \cdot V_A$ involves three variables and therefore requires the use of three potentiometers. R_3 is positioned by D, R_4 is positioned by $1/t_f$, and R_5 by V_A. Therefore, the output of R_5 is proportional to $D \cdot 1/t_f \cdot V_A$. However, the first term $D \cdot R_f$ is added to the output from R_5 producing $(D \cdot R_f) + (D \cdot \frac{1}{t_f} \cdot V_A)$ which is equal to t_fL, lost time of flight.

The third term of the equation is computed by the func-

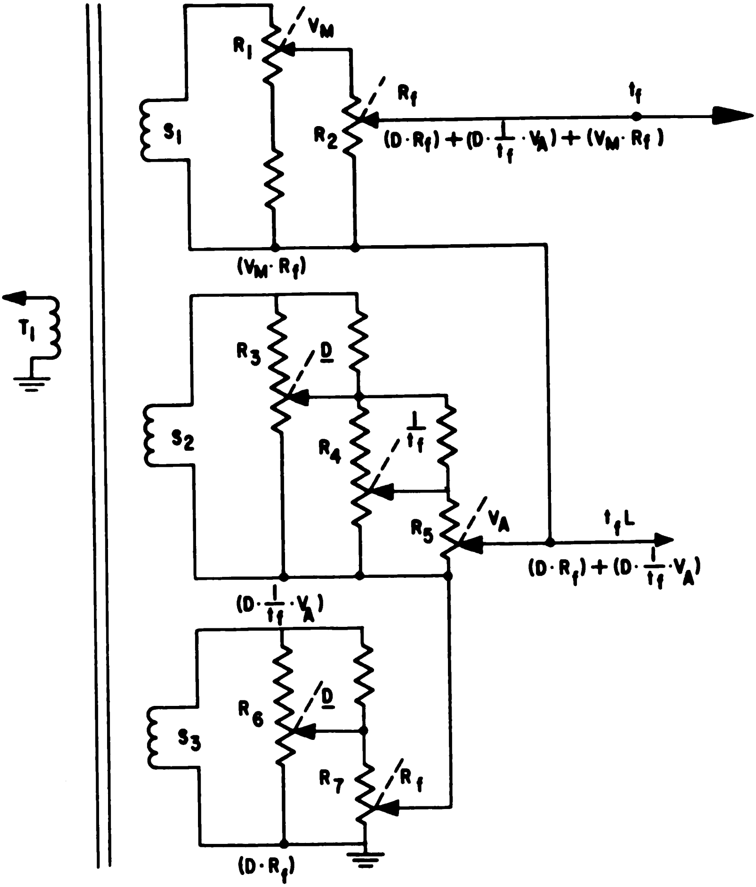


Figure 11–11.—t_f circuit.

tion potentiometers R_1 and R_2. The wiper of R_1 is positioned manually and is proportional to V_m. The V_m signal at the wiper is multiplied by R_f at R_2. Therefore, the signal on the wiper of R_2 is proportional to $V_m \cdot R_f$.

Again referring to figure 11–11, it should be noted that the output of the three sections of the time of flight circuit are connected in series, making the circuit's output proportional to $D \cdot R_f + \frac{D \cdot V_A}{t_f} + V_m \cdot R_f$. Referring to equation

(1), it can be seen that this is equal to t_f and therefore the output of the circuit is t_f. This circuit provides the electrical input to the t_f servo discussed earlier in this chapter.

The ROCKET TIME OF FLIGHT CIRCUIT is essentially the same as the guns circuit and calculates rocket t_f from the equation

$$t_f = R_f + (R_f \cdot T_R) + (R_f \cdot D \cdot V_A) \tag{2}$$

The first term represents t_f in a vacuum and at a specific temperature. The second term provides a temperature correction for the time of flight in a vacuum. The third term represents lost time of flight due to air drag on the rocket. The output of the circuit t_f is transmitted to the inverse time of flight circuit.

GRAVITY DEFLECTION CIRCUITS.—It is also necessary to

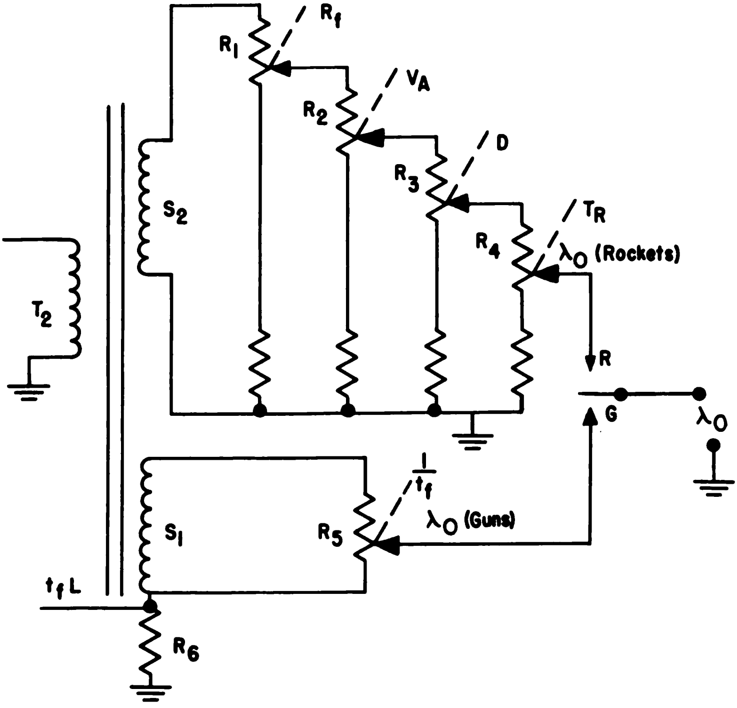


Figure 11–12.—Gravity deflection circuits.

have a separate circuit to produce a signal proportional to gravity deflection λ_o for both guns and rockets. The operation of the circuits is essentially the same as the individual parts of the t_f circuits. Figure 11–12 illustrates the circuits for guns and rockets.

In the GUNS circuit the function potentiometer R_5 is excited by S_1 of T_2 and the t_fL (lost time of flight) signal from the gun t_f circuit is applied at R_6. The output from the wiper of R_5, which is positioned by $1/t_f$, is proportional to λ_o for the projectile being fired.

In the ROCKET circuit the function potentiometers are excited by S_2 of T_2. To obtain a signal proportional to λ_o for the rocket projectile, the circuit multiplies R_f, V_A, D, and T_R. The general equation is:

$$\lambda_o = R_f \cdot V_A \cdot D \cdot T_R$$

The output signal for λ_o from either R_4 or R_5, depending on which weapon is used, is amplified and transmitted to the flight data unit. There it is resolved into its vertical and horizontal components in accordance with the climb and roll attitude of the aircraft. Signals proportional to Λ_{bGA} and Λ_{bGE} are then returned to the computer for use in the ultimate determination of the steering error information.

WINDAGE DEFLECTION CIRCUITS.—To compensate for the effect of windage in computing lead and developing steering error information, it is necessary to utilize two circuits —one for azimuth and one for elevation. Each of these must also have two parts, one for gun and one for rocket operation.

In this course a typical windage circuit will be discussed since the circuits for azimuth and elevation windage are essentially the same. The windage circuits are concerned primarily with the computation of the factor F as discussed in the computer problem section. A_S and A_A are applied to the azimuth and elevation windage circuits respectively where each is modified by the inputs necessary to develop the F factor. The outputs will be Λ_{bWA} and

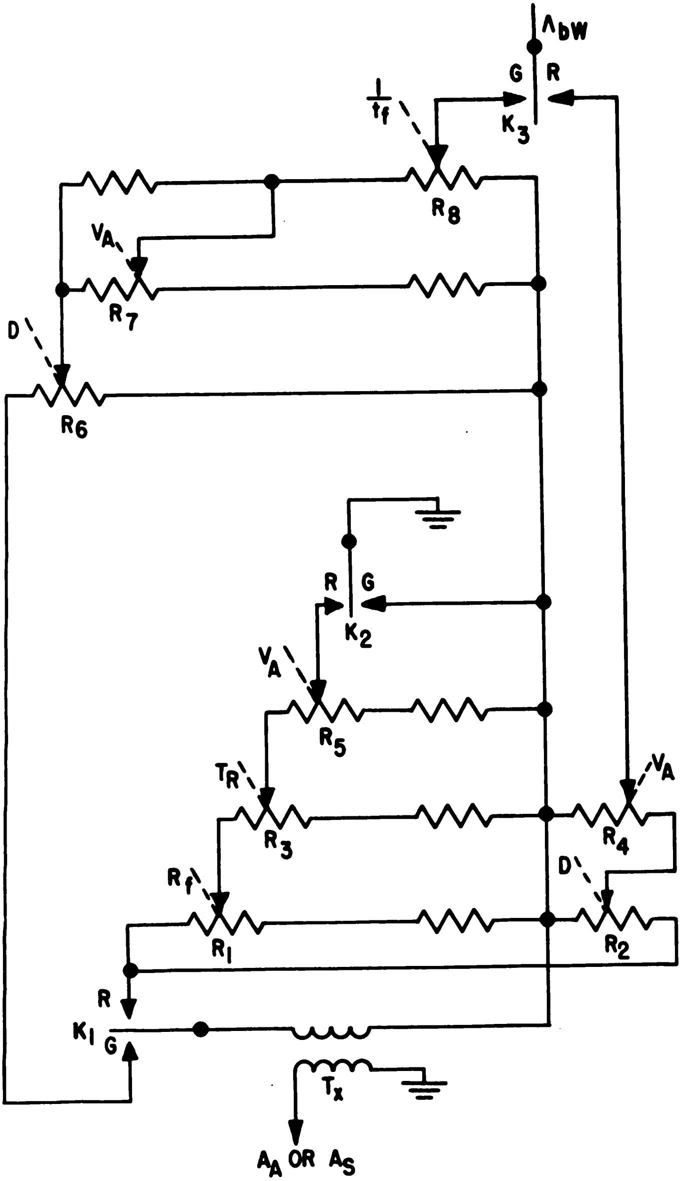


Figure 11-13.—Windage circuits (azimuth and/or elevation).

Λ_{bWE} for azimuth and elevation windage respectively. The general equations solved by each is:

$$\Lambda_{bWA} = A_S \times F$$
$$\Lambda_{bWE} = A_A \times F$$

Figure 11–13 is an illustration of a typical windage circuit. It can be readily observed that the computation is made in this circuit by means of an excitation transformer, fixed resistors, and FUNCTION-WOUND potentiometers controlled by the mechanized variables required. Relays are used to make the selection for either gun or rocket windage computation. The primary difference between the azimuth and elevation windage circuit is the input to the excitation transformer—A_S for the azimuth circuit and A_A for the elevation circuit.

A step-by-step operation of the circuit will not be discussed since the operation is essentially the same as the circuits discussed previously. However, by observation of figure 11–13 it may be seen that the variables contributing to the computation of the F factor for rocket windage are: R_f, T_R, V_A, and D. For the computation of the F

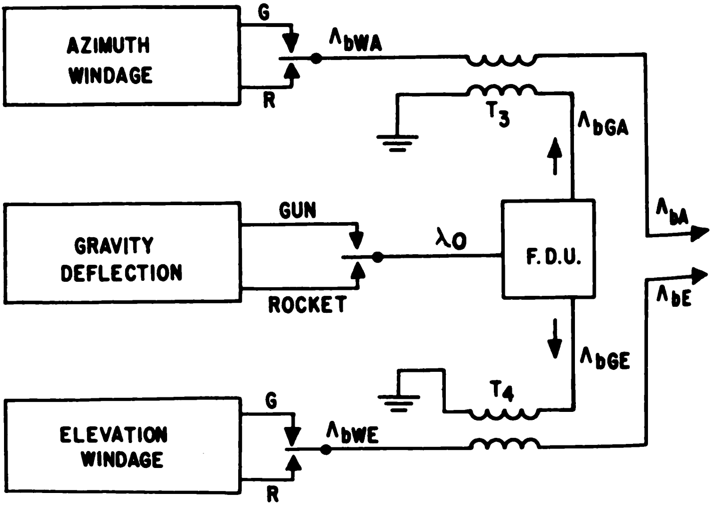


Figure 11–14.—Addition of windage and gravity components.

factor for gun windage, D, V_A, and $1/t_f$ are the variables introduced.

COMBINING WINDAGE AND GRAVITY COMPONENTS.—After each of the individual circuits have developed their respective components of the ballistic lead, it is essential that they be combined. Figure 11–14 is a block diagram showing the manner in which components are combined. This is done essentially by transformers, with windage being applied to one winding and gravity to the other, in both the elevation and azimuth channels. Then the output, vector quantities of ballistic lead, is transmitted to the steering error circuitry.

Steering Error Computation

In the computer problem section it was pointed out that total lead is composed essentially of kinematic and ballistic lead. Thus, since ballistic lead computation has just been discussed, the next logical discussion is that of kinematic lead. However, the computation of kinematic lead by the computer is incorporated with the development of steering error information. This is a design peculiarity; therefore, the computation of kinematic lead by the computer may not be recognized as such in the discussions that follow.

ANALYSIS OF HEADING ERROR.—For a better understanding of the meaning of steering error information, observe and study figure 11–15. Bear in mind that the diagram illustrates the heading error for the horizontal plane; however, it is essentially the same for the vertical plane.

Basically the heading error is the summation of the interceptor heading relative to the target and the computed lead angle. These values would, of course, be instantaneous and continuously changing as the attack progresses. In figure 11–15, the vector OH is the interceptor heading and OC is the heading required by the interceptor to be leading the target by the correct amount.

Thus, the summation of the antenna position angle P_A and azimuth lead angle Λ_A produces the heading error E_{HA}. This information, when filtered, amplified, and transmitted

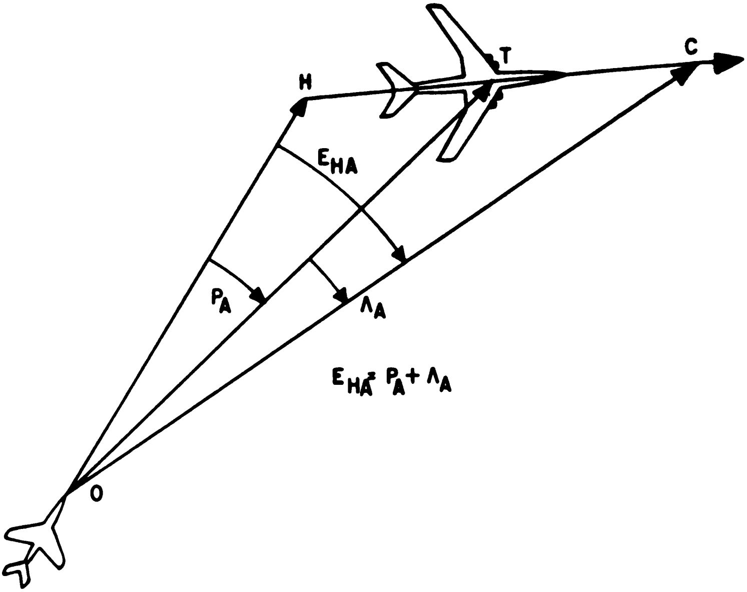


Figure 11–15.—Vector analysis of heading error.

to the pilots indicator, is the steering error information for the horizontal plane observed by the pilot.

STEERING ERROR CIRCUIT.—Steering error is developed in separate channels for azimuth and elevation with each channel supplying two outputs. One output is for the deflection of the steering circle and the other is for the deflection of the steering dot. The azimuth and elevation channels are essentially the same in construction and operation. Therefore, only one channel will be discussed. Thus, the inputs and outputs as indicated on the circuit diagram may be subscripted either *A* or *E* for the channel desired.

As shown by figure 11–16, the steering error channel circuitry is divided primarily into three parts: antenna position resolver, summing network, and output amplifier. There would, of course, be one of each for both the elevation and azimuth channels.

The computed ballistic lead Λ_b is applied to one winding of the antenna position resolver. The resolver is

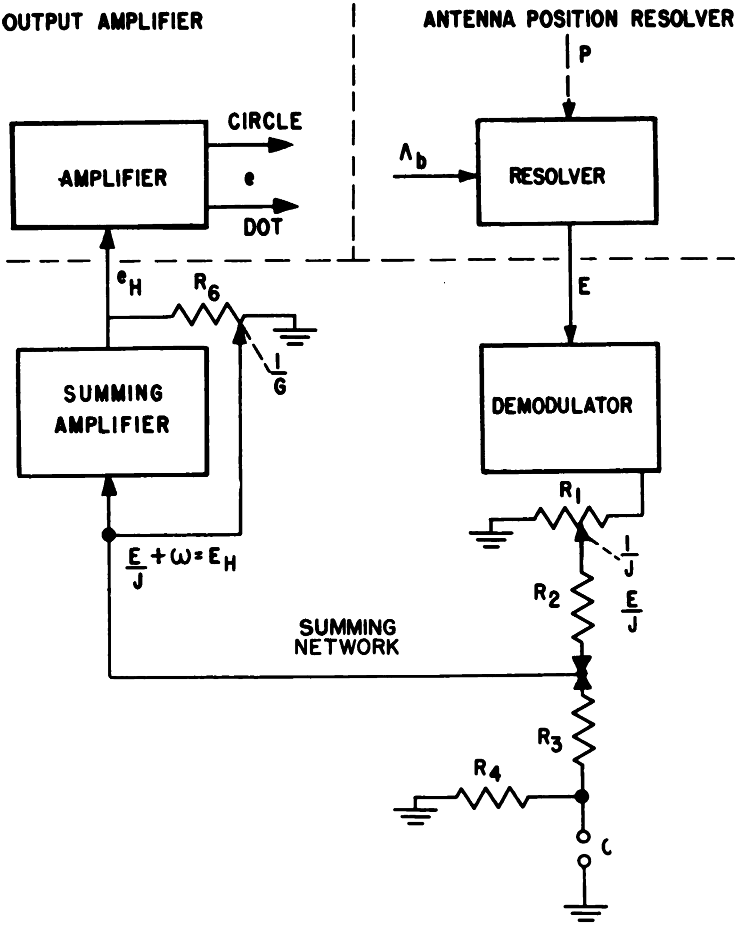


Figure 11–16.—Steering error circuit.

mounted on the antenna and therefore the angular position of the target P (relative to the interceptor) is mechanically introduced. The quantities Λ_b and P are combined in the resolver and the output is a complex voltage analog represented by E. This is referred to as the ERROR TERM.

The error term E is applied to a demodulator, the output of which is multiplied by $1/J$ by potentiometer R_1. Thus,

E/J is applied to the summing point across R_2. The angular velocity of the line of sight ω is also applied to the summing point across the resistive network R_3 and R_4. Thus, the resultant of the summation at the summing point is the desired heading error E_H. Therefore:

$$E_H = E/J + \omega \tag{3}$$

This is essentially the same equation as

$$E_H = P + \Lambda \tag{4}$$

which is illustrated in figure 11–15.

It should be recalled that

$$\Lambda = \Lambda_b + \Lambda_k \tag{5}$$

and

$$\Lambda_k = J \cdot \omega \tag{6}$$

Therefore,

$$\Lambda = \Lambda_b + (J \cdot \omega) \tag{7}$$

Inserting this equation into equation (4) will result in

$$E_H = P + (\Lambda_b + J \cdot \omega) \tag{8}$$

Therefore, since Λ_b and P have been combined in the resolver producing the error term E,

$$E_H = E + (J \cdot \omega) \tag{9}$$

In the design of the computer ω was not multiplied by the factor J, but instead E was multiplied by the factor $1/J$. Therefore, the solution for E_H by the computer (equation 3) should be proportional to the solution for E_H by equation 9.

The heading error signal E_H is applied to the summing amplifier which provides isolation from the summing network. The output of the summing amplifier is multiplied by the gain term $1/G$. The potentiometer R_6 in the feedback network of the summing amplifier introduces this term to the circuit. The steering error e_H, which is essentially the processed heading error E_H, is applied to the output amplifier. Two proportional outputs are taken from it by means of a plate circuit voltage divider and are transmitted to the indicator where the steering error information is displayed by means of a circle and dot deflection.

MAINTENANCE

The computer discussed in this chapter is designed to provide maximum accessibility for ease of maintenance. It is sectionalized and the individual sections are hinged to permit ready access to the terminals, components, etc., beneath the chassis. Many molded plug-in type units are employed, thus simplifying maintenance work considerably. (NOTE: A molded plug-in unit normally consists of a subassembly or assembly that has been encased in molded plastic or similar material. The unit contains a plug for connecting it to the other circuits.) Ganged screwdriver-adjusted potentiometers are also employed to a considerable extent. The discussion of maintenance on the computer will be generalized and the technician should bear in mind that the *Handbook of Service Instructions* should always be consulted for the computer to be maintained.

Preventive Maintenance

This type of maintenance is performed to detect any degradation in performance or physical condition of the computer. It is also performed as an aid in preventing possible malfunctioning which might be serious, thus lengthening the trouble-free operating period and prolonging the useful life of the computer.

PERIODIC INSPECTIONS.—Periodic in spections are the most effective instruments used by the technician in carrying out preventive maintenance. These periodic inspections may be incorporated in the periodic inspections designed for the system in which the computer is a functional component.

These periodic inspections will normally coincide with the preflight, intermediate, and major inspections of the aircraft. The degree or thoroughness of the inspection will vary from the preflight to the major inspection. At the time of the major inspection, the most comprehensive performance tests will be carried out.

The PREFLIGHT inspection is essentially an operational check performed in the cockpit of the aircraft. It consists primarily of quick checks on the computer's solution of the built-in test problems, for each mode of operation. The rocket launching and anticollision circuits must also be checked during this inspection.

The INTERMEDIATE inspections are considerably more detailed than the preflight inspection and more attention is given to the material condition of the components of the computer. These inspections may require the use of portable test equipments for checking some sections of the computer while it is installed.

The MAJOR inspection is primarily a bench check involving both a visual inspection and performance test. Several of the major steps in making this inspection are:

1. Removal of the computer from the aircraft and installation in the shop bench test setup.
2. Make a visual inspection for defects.
3. Preparation of the bench test setup.
4. Check ALL regulated power supplies that will be involved during the inspection.
5. Perform the static test problems.
6. Check built-in test, rocket launching, and anticollision circuits.
7. Replace the computer in the aircraft and insure that the controls are set for the armament in use.

PREPARATION FOR BENCH TEST.—Each time that a computer is removed from an aircraft for bench checking, certain procedures must be observed; therefore, all applicable *Handbooks of Service Instructions* should be consulted. All tools and test equipment must be obtained and set up where they will be needed. A special computer test set will usually be required which will furnish all the inputs and control signals needed to perform the bench test on the computer. When a computer of this type is placed on a bench for testing, it is essential that provisions be made for cooling by directing an airstream from an auxiliary fan or blower at the computer while it is under test.

Prior to making all the required interconnections between the computer, test equipment, and power supply, it is

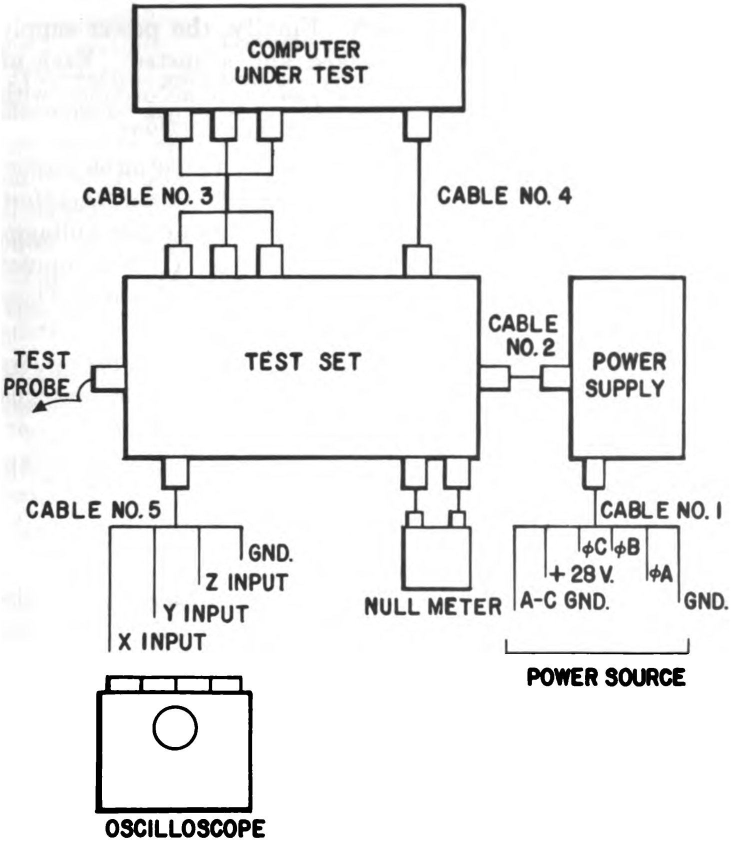


Figure 11–17.—Bench test setup.

important to insure that ALL switches are in the OFF position unless otherwise specified. Figure 11–17 is an illustration of how a computer of this type might be interconnected for a bench test.

Before beginning the tests on the computer it is essential that ALL THE POWER SUPPLIES BE CHECKED to insure that their outputs are within tolerance. The power supply for the bench test setup should first be checked and adjusted when its outputs are not within specified tolerances. Following this, the power supply within the computer test set must be checked and adjusted. Finally, the power supply in the computer must be checked and adjusted. Each of these should be checked and adjusted in accordance with the applicable *Handbook of Service Instructions.*

These checks and adjustments are of the utmost importance, as the overall accuracy of the test set and therefore the computer is dependent upon the use of proper voltages.

STATIC TEST PROBLEMS.—Overall testing of the computer is accomplished with the use of static test problems. These problems are the primary tools of the technician in making routine performance tests while carrying out preventive maintenance. Fixed values of range, range rate, antenna position, airspeed, temperature, and other quantities normally furnished by system components to the computer are simulated and supplied by the computer test set. The test set requires that the values be set in manually and the results interpreted by the operator.

The computer's solution of the test problem fed into the computer is presented on an oscilloscope, which monitors the outputs of the azimuth and elevation steering error channels. When correctly solved by the computer, a test problem produces a zero deflection of a dot on the oscilloscope.

The *Handbook of Service Instructions* will contain charts consisting of several test problems for use in checking the computer's accuracy. Normally, there will be a chart for each type of attack course and each chart will have several problems for each type of armament and variation of that armament. It will not be necessary to run all of the test problems but a sufficient number and variety of problems must be run to verify that the computer is performing satisfactorily for representative armament and course combinations.

In addition to testing the lead pursuit and lead collision modes, the built-in test contained in the rocket launching and anticollision circuits must also be checked as a part of the performance test.

Corrective Maintenance

Corrective maintenance must be performed whenever a discrepancy appears in any of the previously mentioned inspections or on the daily "gripe" sheet. It consists essentially of trouble analysis or isolation, repair or replacement of defective units, and alinement or adjustment of the computer after corrective action has been taken.

Trouble analysis.—Trouble analysis procedures are inseparable from test problem procedures and individual circuit tests. A thorough understanding of the relationships between the various mechanized variables should lead to a method of troubleshooting by elimination.

When trouble develops in the computer one of the first things to check is its regulated power supply. Then consider the molded units and tubes in circuits of questionable performance which can be replaced and tested later. Do not attempt to perform detailed troubleshooting in a circuit until the presence of a trouble has been definitely established in that circuit.

If the presence of trouble in the computer was first indicated by results of the static test problems discussed in preventive maintenance, the next step is to perform the trouble analysis test problems. However, the trouble analysis test problems must be run in conjunction with the static test problems.

The test problem trouble analysis chart found in the *Handbooks of Service Instructions* contains additional voltage information for the various test points for each problem listed in the test problem chart. These charts, used in conjunction with the servo dial readings, will provide a systematic means of isolating trouble to a specific circuit. The values given in the charts are nominal d-c and a-c r.m.s. voltages and should be used only as a guide. If the exact voltage is not obtained, it is not necessarily an indication of a faulty circuit. However, if no voltage is present where voltage is indicated on the chart, or if the measured voltage differs greatly from the nominal value, trouble should be suspected at that point. Then, working from a functional block diagram, the individual circuits involved in providing that quantity should be checked in detail.

Before beginning detailed troubleshooting, recheck the inputs to the computer. In many cases the trouble is caused by incorrect settings of the test set controls; also check the dial servo readings. Both d-c and a-c voltages should be measured with a VTVM. The sign of the terms represented by the a-c voltages can be determined with the use of an oscilloscope and the intensity pulse provided by the computer test set.

INDIVIDUAL BENCH TESTS AND ALINEMENT.—Individual bench tests and alinement tests should be performed on systems within the computer after field changes and repairs have been made, or when minimum performance tests and/or troubleshooting reveals their need. Many of the tests and adjustments will be relatively simple and easily accomplished while others may be interdependent, one upon the other. However, when performing detailed troubleshooting or alinement, the applicable *Handbook of Service Instructions* should always be consulted for proper procedures and adjustments. A typical list of the TYPES of tests and adjustments might be:

1. Amplifiers.
2. Servo systems.
3. Demodulator balance.
4. Ballistic circuits.

The technician should bear in mind that there may be several types of the various items listed above and, therefore, quite possibly an equal number of different procedures.

REPAIR AND REPLACEMENT OF UNITS.—Any component, unit, or part that is found to be defective at any time should, of course, be repaired or replaced. An item may be defective for any number of reasons; therefore, it is impractical to state when an item should be repaired or replaced. The inexperienced technician should consult the *Handbook of Service Instructions*, existing instructions, and his immediate superior when there is a question as to what action is most appropriate.

QUIZ

1. The electromechanical computer discussed in this chapter is used to compute lead angle with which of the following?
   - a. Guns only
   - b. Guns and rockets
   - c. Rockets only
   - d. Visual, air-to-ground problems
2. With the steering dot in the center of the steering circle, the gun line is pointing
   - a. directly at the target
   - b. behind the target
   - c. below, and leading the target
   - d. above, and leading the target
3. The purpose of the electromechanical computer is to supply the pilot with
   - a. steering information
   - b. the computed lead angle
   - c. the antenna position
   - d. ballistic lead only
4. An outstanding characteristic of this computer is its use of
   - a. servo systems
   - b. gyro assemblies
   - c. a small power supply
   - d. tubes as computing devices
5. Outputs of the antenna resolver are
   - a. E_E, P_E, and P_A
   - b. Δ_{bA}, Δ_{bE}, and E_R
   - c. E_R, E_A, and E_E
   - d. P_A, P_E, and Δ_{bA}
6. The computer has three modes of operation which are
   - a. lead pursuit for guns or rockets and lead collision for guns
   - b. lead collision for guns or rockets and lead pursuit for rockets
   - c. lead pursuit for guns or rockets and dive angle for bombing
   - d. lead pursuit for guns or rockets and lead collision for rockets

7. In the computation of steering error the output of the summing network is fed to the
   a. $\frac{1}{J}$ servo
   b. $\frac{1}{t_f}$ servo
   c. antenna position resolvers
   d. output amplifier

8. Total lead angle is equal to
   a. $A_{kA} + A_{bA}$
   b. $A_{A} + A_{E}$
   c. $A_{kE} + A_{bE}$
   d. $A_{bE} + A_{b}$

9. Ballistic lead angle is equal to
   a. $A_{bE} + A_{bA}$
   b. $A_{bWE} + A_{bGE}$
   c. $A_{bE} + A_{bGA}$
   d. $A_{bWA} + A_{bG}$

10. This computer contains _____ servo systems
    a. 4
    b. 5
    c. 6
    d. 7

11. Air density D is computed as a function of
    a. static air pressure, indicated air temperature, and ram-air temperature
    b. static air pressure, and indicated airspeed
    c. airspeed, cockpit temperature, and ram-air temperature
    d. static air pressure and ram-air temperature

12. The output of the error detector in a servo system used for computing is ______________________ when the equation is solved.
    a. a positive voltage
    b. a negative voltage
    c. zero
    d. an a-c voltage of maximum amplitude

13. How many time-of-flight circuits are in this computer?
    a. 1
    b. 2
    c. 3
    d. 4

14. Preventive maintenance is performed on this computer to
    a. detect any decrease in performance
    b. correct a malfunction
    c. keep the maintenance men busy
    d. analyze a malfunction

15. In a lead collision course, the rocket launcher is aimed at a point determined by
    a. kinematic lead plus windage and gravity corrections
    b. ballistic lead plus windage and gravity corrections
    c. windage and gravity corrections
    d. windage, drift, and gravity corrections

16. Information from the director is used to position
    a. the gyro "pipper" in a sight unit
    b. the gyro "pipper" in a sight unit or the circle and dot in the radar indicator
    c. the circle and dot in the radar indicator
    d. the aircraft so the guns or rockets will bear on the target

17. Gravity deflection computed by the director is resolved into its elevation and azimuth components in the
    a. radar set
    b. vertical gyro
    c. antenna
    d. flight data unit

18. The advantage of lead collision solution over other possible solutions is that it
    a. may be used for greater ranges
    b. enables attacker to approach at an angle outside the maximum defense zone
    c. enables attacker to obtain a higher degree of accuracy with guns
    d. takes advantage of the smaller closing rate involved in the solution

19. The lead pursuit course type of attack is advantageous in developing a lead angle for
    a. guns only
    b. rockets only
    c. missiles only
    d. guns and rockets

20. The calculated total lead angle is composed of two primary factors. They are
   a. gravity lead and ballistic lead
   b. kinematic lead and ballistic lead
   c. kinematic lead and windage
   d. ballistic lead and gravity lead

21. The J factor is employed in the computer solution to represent
   a. $\dfrac{Rt_f}{R_f}$
   b. $\dfrac{R_f}{Rt_f}$
   c. $\dfrac{Rt_f}{R_f + V_A t_f}$
   d. $\dfrac{R_f + V_A t_f}{Rt_f}$

22. Most electromechanical analog computers employ which of the following methods of inserting a given quantity at several places simultaneously?
   a. Multiple coupling capacitors
   b. Voltage dividers
   c. Ganged potentiometers
   d. Multipole motors

CHAPTER 12

MECHANICAL COMPUTER

The computer to be discussed in this chapter is essentially an electro-mechanical analog computer. It is a type of calculating machine that operates with numbers represented by directly measurable quantities as voltages, resistances, shaft rotations, etc. It is typical of the type used for the solution of high altitude precision bombing problems.

It provides a means for offset bombing, where the aim point is other than the target. The computer may also be used as an aid to navigation, as it furnishes direct readings of latitude and longitude at all times.

The greatest difference between this computer and others studied thus far in this course, other than type of computer, is its installation. This computer must be located so that its front panel will be easily accessible to an operator. This is essential because the controls located on the front panel must be preset and observed during the bombing mission. These controls are used for the solution of the bombing problem and as an aid to navigation. Figure 12–1 illustrates the computer's front panel showing the operator's controls and indicators.

THE COMPUTER PROBLEM

Before considering the operation of the computer we shall first discuss the problem which it must solve. The bombing problem is concerned primarily with the physical principles involved when a bomb is dropped from an aircraft operating at high speed and high altitude. The

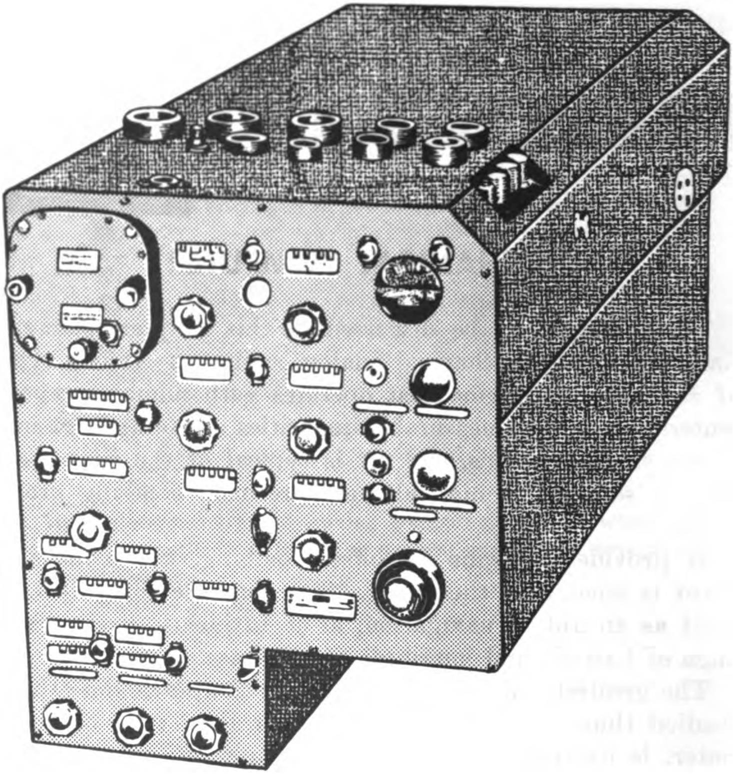


Figure 12–1.—Mechanical computer.

rudiments of the bombing problem were discussed in the section entitled "Horizontal Bombing" in chapter 3 of *Aviation Fire Control Technician 3*, NavPers 10388. It is suggested that this section be reviewed to facilitate the understanding of the following sections.

The Bombing Problem

The problem, in general, is determining what course to fly, and at what point along this course the bomb must be released. A three dimensional view of the bombing problem is shown in figure 12–2.

Referring to figure 12–2, note that the aircraft, now at

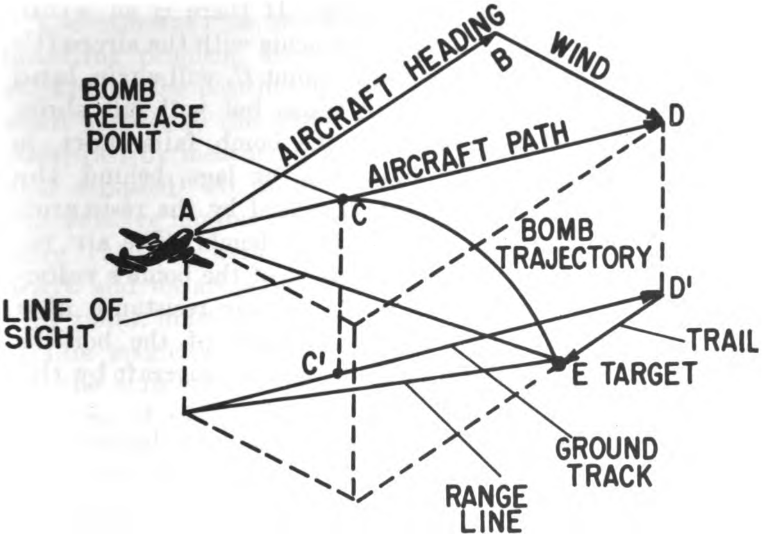


Figure 12–2.—The general bombing problem.

point *A*, is heading toward point *B*, but a cross wind is blowing in the direction *B* to *D*. The aircraft's path, projected down along the ground, is referred to as the ground track. Assuming that all conditions are correct, a bomb released from the aircraft at point *C* will land at point *E*, the target.

Let us briefly review the basic bombing problem to insure a thorough understanding of the bombing problem. If an aircraft were traveling in a vacuum, its heading would coincide with its ground track. With this stipulation in mind, a bomb released at point *C* would land at point *D*' on the ground track. Because gravity accelerates the bomb in the downward direction, and because of the initial horizontal velocity imparted to the bomb by the motion of the aircraft, the bomb will land at point *D*' at the same instant the aircraft reaches point *D*. In other words, the bomb, as it is falling to the ground, will remain at all times directly beneath the aircraft.

Under actual conditions, however, the situation is altered by the presence of the atmosphere. If there is no wind, the aircraft's heading will again coincide with the aircraft's path. The same bomb, released at point *C*, will again land at some point along the ground track, but will fall short of point *D'*. The amount that the bomb falls short is termed TRAIL, since the bomb trails, or lags, behind the aircraft by this amount. Trail is caused by the resistance of the air opposing the motion of the bomb. The air resistance acts on the vertical component of the bomb's velocity to lengthen the time of fall. The air resistance also acts to reduce the horizontal component of the bomb's velocity, causing the bomb to lag behind the aircraft by the amount called trail.

With a wind blowing in the direction *B* to *D*, the aircraft must be headed somewhat into the wind so that it traverses the desired course from *A* to *D*. A bomb released at point *C* will be affected by air resistance as before and, in addition, will be displaced from the ground track by the wind. The bomb will always trail the aircraft in the direction opposite to that of the aircraft's heading.

Thus, if the ballistic behavior of the bomb, the magnitude and direction of the wind, and the direction of approach to the target are known, the release point may be determined as well as the exact flight path for the bomb run.

Solution of the Bombing Problem

From the foregoing discussion it is evident that the bombing problem breaks down into two basic parts—the tracking problem and the release point problem. Added to these is the problem of stabilization, that is, the provision of a stable reference frame. (A reference frame of the type employed here was discussed in chapter 7 of this course under stabilizing gyros.) The bomb director performs these computations in a manner which enables the pilot to make any necessary evasive maneuvers; however, it is necessary for the aircraft to be on course at the instant the bombs are released.

Development of tracking data.—In order to solve the bombing problem, accurate information must be obtained regarding the position of the aircraft and how it is moving with respect to the target or aim point. Tracking data is compiled by measuring continuously the aircraft's heading and airspeed. At the same time, observations are taken on the relative motion between the aircraft and the aim point. Any variation between the computed position of the aircraft and its actual position, observed with respect to the aim point, must be caused by wind.

The magnetic heading of the aircraft θ_m is determined by the stabilizing system. (The heading stabilizing system was discussed in detail in chapter 7 of this course.) The aircraft's true heading θ is determined in the computer by combining magnetic variation y with θ_m.

Figure 12–3 illustrates some of the important vector quantities and angles associated with the solution of the bombing problem. It is assumed that the aircraft is viewed from above and all angles are measured in a clockwise direction as shown, except y which may be in either direction.

True airspeed V_A is computed by using information obtained from the aircraft's pitot-static system and is plotted in the same direction as the aircraft's heading. Some value of wind will cause the aircraft to drift from its heading, resulting in a ground track as shown in figure 12–3. The velocity of the aircraft along the ground track V_G is not equal to V_A due to the effect of wind. V_G is computed by taking the vector sums of V_A and wind velocity V_W. V_W is resolved into two right angle components ${}_RV_W$ and μV_W as shown in figure 12–3. The range wind component ${}_RV_W$ is plotted parallel to the range line, and the cross wind component μV_W is plotted perpendicular to the range line. Thus, V_G is the vector sum of the vector quantities V_A, ${}_RV_W$, and μV_W.

A horizontal line from a point directly beneath the aircraft to the aim point is referred to as the range line. From a study of figure 12–3, it can be seen that R and μ are continually changing because of the motion of the air-

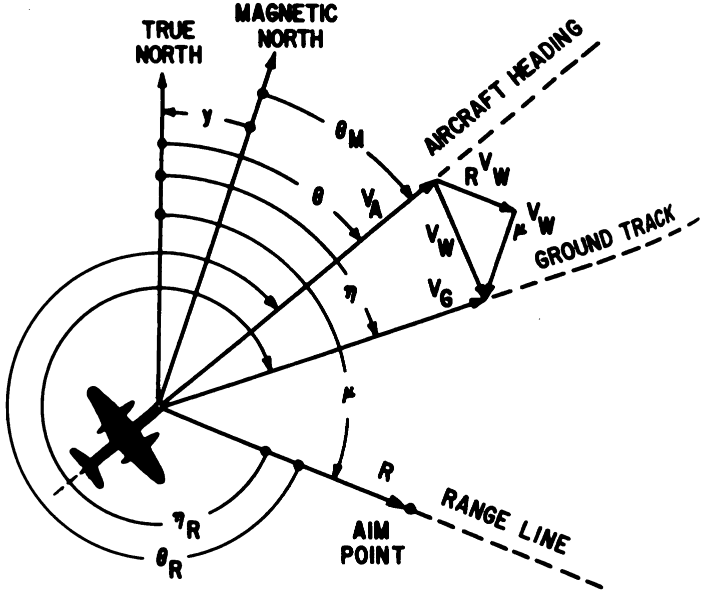


Figure 12–3.—Important angles associated with the bombing problem.

y	Magnetic variation.
θ	True heading of the aircraft.
θ_m	Magnetic heading of the aircraft.
θ_R	Relative bearing—angle between the line of sight and the aircraft's heading.
η	True course—angle between true north and ground track.
η_R	Relative course—angle between range line and ground track.
μ	True bearing of aim point—angle between true north and range line.
V_A	True airspeed.
V_W	Velocity of wind.
$_RV_W$	Range wind.
$_\mu V_W$	Cross wind.
V_G	Groundspeed.
R	Horizontal ground range.

craft. The rates at which R and μ change constitute the crux of the tracking operation since these rates represent the motion of the aircraft with respect to the aim point.

Tracking of the aim point is initiated by the operator who positions a set of cross hairs on the aim point while on optical operation. During radar operation, he positions the intersection of a range line and a bearing line on the aim point appearing on the radar indicator. If the values of V_G, R, ηR, and μ are correct, the cross hairs or range and bearing lines will remain on the aim point. Under these conditions the equipment is said to be TRACKING the aim point.

If these values are not correct, the cross hairs or range and bearing lines will drift off the aim point, indicating that these values do not coincide with the observed conditions. This difference is caused by the use of incorrect values of wind components (wind rates) in the computations; thus, the operator must correct these values in order to track the aim point.

During optical or radar operation, the wind rates are corrected by first placing the cross hairs on the aim point, allowing them to drift for a short time interval and then replacing them on the aim point. The amount of change in R and μ required to replace the cross hairs on the aim point, divided by the amount of time the cross hairs are allowed to drift, is measured by the equipment and entered as wind rate corrections. With correct wind rates, the bomb director is able to track the aim point and thereby develop accurate values of V_G, R, η_R, and μ.

DEVELOPMENT OF RELEASE POINT DATA.—Most of the information required in the development of release point data has been introduced as tracking data. Additional information is required as follows:

1. Altitude of the aircraft above the target. It is found by subtracting the elevation of the target H_T from the altitude of the aircraft H_O.
2. Vertical component of aircraft velocity V_H.
3. Bomb ballistic setting T.
4. Horizontal offset distance from aim point to target S.
5. Angle between true north and the horizontal position of the S vector ψ.

All the information listed above is used ultimately to produce two vectors known as the A vector and the B vector. These two vectors are then compared to obtain an indication of the course correction required for a bomb to hit the target and the distance to the bomb release point.

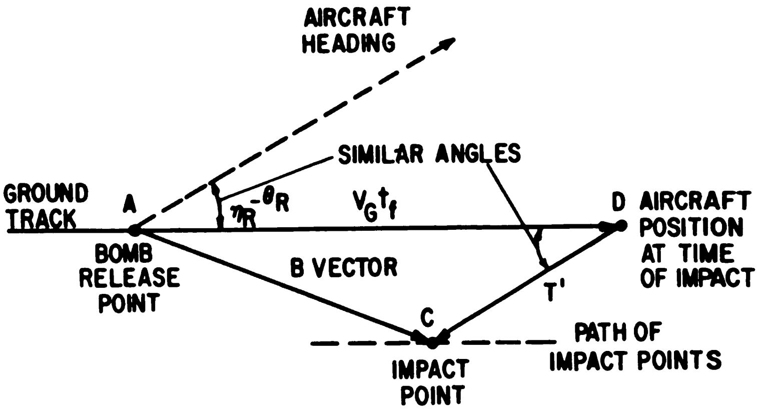


Figure 12–4.—*B* vector diagram.

In the discussion that follows, each vector will be discussed separately, and then the method of comparison will be explained.

The B VECTOR is established to continuously determine where the bomb would strike the ground if it were to be released at the present position of the aircraft. Figure 12–4 illustrates the establishment of the B vector.

The B vector represents the horizontal distance between the release point and the impact point, and the direction of the impact point relative to the release point. The B vector cannot be established directly; the other two sides of the triangle must be computed first. The $V_G t_f$ vector must be projected ahead of the aircraft, along the ground track; then the magnitude of the T' vector and the angle it makes with the $V_G t_f$ vector must be determined.

The $V_G t_f$ vector represents the distance the aircraft will travel during the time of fall of the bomb, t_f, and is computed by multiplying V_G times t_f. V_G was computed in the tracking data computing system, but t_f is computed in the release point data computing system from values of V_H, $H_O - H_T$, and T.

The T' vector represents the distance between the aircraft position and the point of impact at the time of impact, and is computed from values of $H_O - H_T$, V_A, and T. The angular displacement of the trail vector from the ground track is equal to the angular displacement of the aircraft heading and the ground track, which is the difference between η_R and θ_R.

Having established two sides of the triangle, the *B* vector may be established by constructing a line between the bomb release point and the impact point. It should be noted that these vectors have all been projected ahead of the aircraft, and if a bomb is released at point *A*, it will strike the ground at point *C* at the same time the aircraft reaches point *D*. If these calculations are projected continuously, a plot of impact points will lie along a line parallel to the ground track as shown in figure 12–4.

The *A* VECTOR represents the following:

1. The direction of the target from the present position of the aircraft.

2. The horizontal distance between the present position of the aircraft and the target.

Figure 12–5 illustrates the relationship between the target, aim point, and present position of the aircraft.

It should be noted that the *A* vector cannot be determined directly. It must be derived by construction after establishing the other two sides of the triangle which represent the quantities *R* and *S*. The horizontal range *R*, which represents the distance between the present position of the aircraft and the aim point, is computed by the track-

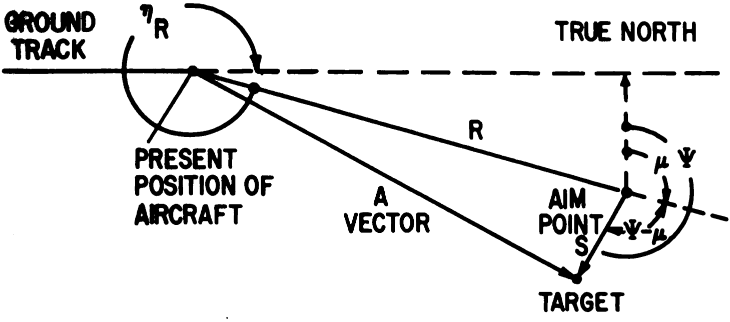


Figure 12–5.—The *A* vector diagram.

ing data computer. Relative course η_R provides the release point data computer with the necessary information to allow the computer to construct the line *R* (length and direction). Should the aim point and the target be the same, the *A* vector would be the same as the line *R*. However, with offset bombing, additional information must be used to construct a triangle giving the *A* vector. *S*, the distance between the aim point and the target, and its position relative to true north (angle ψ) must be supplied the computer. The line connecting the two points constitutes the second line of the triangle, thus providing sufficient data for the construction of the *A* vector. Now that a solution for the *A* vector has been discussed, it should be remembered that it is a continuous process since its magnitude and direction change as the aircraft approaches its target or changes its heading.

The *A* AND *B* VECTOR COMPARISON is now necessary for the final solution of the bombing problem. The *B* vector has been established to predict where the bomb would strike if dropped from the present position of the aircraft. The *A* vector has been established to show the position of the target with respect to the present position of the aircraft. If these two vectors can be made to coincide exactly, the bomb can be dropped with the expectation that it will strike the target. Therefore, the remaining problem for the computer is to compare the vectors and supply the pilot

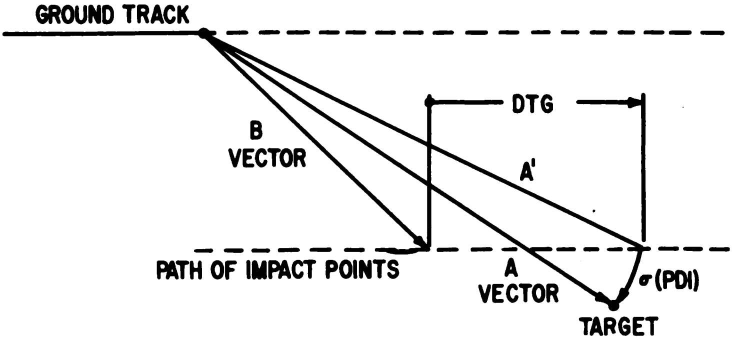


Figure 12–6.—Comparison of the *A* and *B* vectors.

with the heading correction and distance to go to the release point. The pilot must then maneuver his aircraft so as to bring the path of impact points across the target before the aircraft reaches the release point. By observing figure 12–6, it should be obvious that the *A* and *B* vectors cannot be made to coincide without a change in the aircraft's heading. Therefore, the computer must determine the extent of the correction and transmit this data to the pilot.

COMPUTER BLOCK DIAGRAM

The computer consists of two computing assemblies which shall be called TRACKING DATA COMPUTER and RELEASE POINT DATA COMPUTER. The purpose of the tracking data computing system is to continuously track the aim point and provide the release point data computer with data used in the solution of the bombing problem. The release point data computer actually solves the bombing problem based on the input data from the other systems. It provides a continuous solution to the impact point of the bomb which has previously been discussed as the *B* vector.

However, before going further into the two computing assemblies, we shall consider their relationshp to the other systems of the bomb director. Figure 12–7 is a block diagram showing the various systems and the flow of data from one system to another.

Referring to figure 12–7, it should be noted that the director contains three systems which supply data, either directly or indirectly, to the tracking data computer and the release point data computer. The systems are:

1. Optical system.
2. Radar system.
3. Stabilizing system.

The OPTICAL SYSTEM is the sighting element for optical tracking. It establishes the line of sight and indicates any difference between the line of sight and the line to the aim point, this difference being tracking error.

The RADAR SYSTEM is the sighting element for radar track-

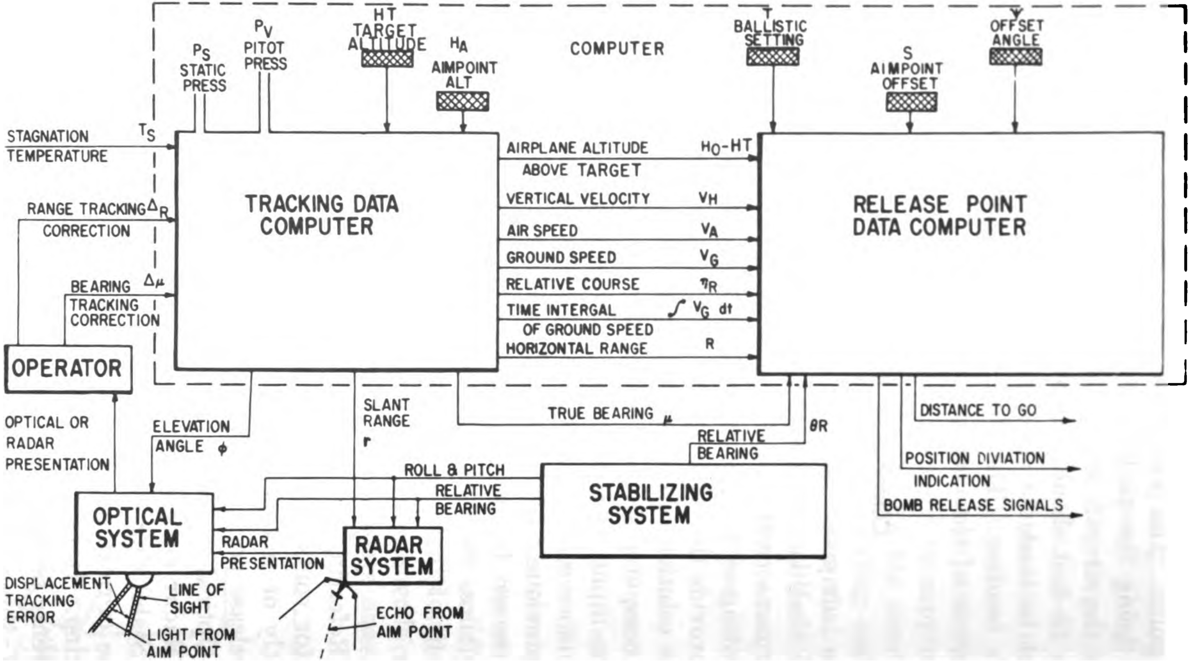


Figure 12–7.—Basic block diagram of a bomb director.

ing. It measures slant range and relative bearing of the aim point and receives computed values of these quantities from the tracking data computer and the stabilizing systems. Any differences between measured and computed values (tracking error) are indicated as displacement of the aim point image from the intersection of the radar crosslines. The operator, observing either optical or radar presentation, concurrently makes range and azimuth tracking corrections to keep the aim point image at the intersection of the crosslines.

The STABILIZING SYSTEM maintains radar and optical lines of sight fixed in space despite movements of the airplane about its roll, pitch, and azimuth axes. A system of three gyros accomplishes stabilization by establishing a stable platform and reference direction, and measures the airplanes rotations about these stable axes. Measured values of roll, pitch, and relative bearing are fed to the optical and radar systems.

TRACKING DATA COMPUTER

The preceding section discussed the function of the tracking data computer. In this section we shall discuss its operation.

To solve the bombing problem it is necessary to determine the relative motion between the aircraft and the aim point. Consequently, it is necessary to track the aim point to generate the required information regarding aim point location and relative motion needed for (1) the release point data computer, (2) navigation, and (3) maintaining the line of sight on the aim point.

Tracking means placing the line of sight on a selected aim point and altering the values of certain variables in the tracking data computer so that the line of sight remains on the aim point. If the line of sight drifts off the selected aim point, the procedure of resetting it corrects the values of the variables in the tracking data computer so that it will remain on the aim point.

The tracking data computer has several functions. They are as follows:

1. SEARCH—when information is needed for locating an aim point during an attack or for identifying landmarks.
2. TRACKING—for precision determination of relative motion and position data.
3. ALTITUDE CALIBRATION—which is the checking of the altitude by radar to make corrections to the measured pressure altitude in the computer.

Required Input Data and Outputs

The inputs to the tracking data computer may be observed in figure 12–7. They are:

1. Tracking correction signals, range and bearing (ΔR and $\Delta\mu$).
2. Static pressure P_S.
3. Pitot pressure P_V.
4. Stagnation temperature T_S.
5. Aim point altitude H_A.
6. Magnetic variation y.
7. Target altitude H_T.

The outputs of the tracking data computer are:

1. Slant range r.
2. Elevation angle ϕ.
3. Tracking data supplied to the release point data computing system as follows:
   a. Groundspeed V_G.
   b. True bearing μ.
   c. Horizontal range R.
   d. Relative bearing θ_R.
   e. Airspeed V_A.
   f. Vertical velocity V_H.
   g. Airplane altitude above target $H_O - H_T$.

Functional Systems

To facilitate understanding, the tracking data computer shall be discussed in terms of seven subordinate functional systems. However, the term SYSTEM, which appears re-

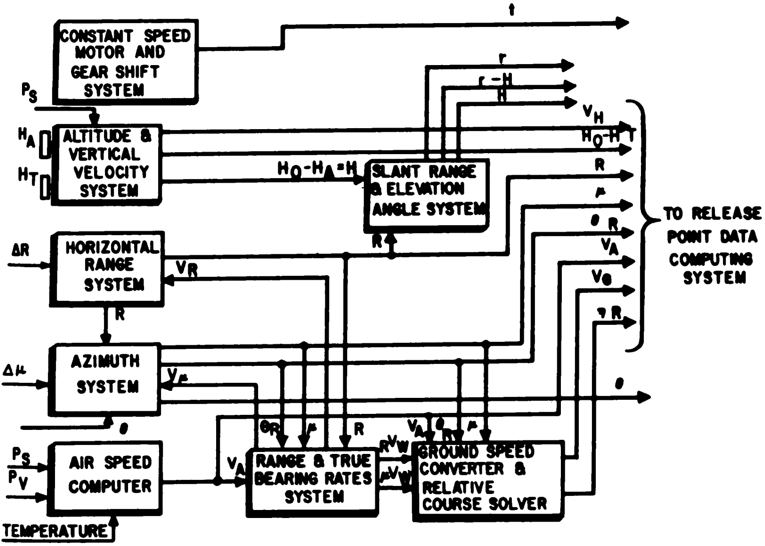

t
CONSTANT SPEED MOTOR AND GEAR SHIFT SYSTEM
r
r - H
H
V_H
H_O-H_T
R
μ
θ_R
V_A
V_θ
ηR
TO RELEASE POINT DATA COMPUTING SYSTEM
P_S
H_A
H_T
ALTITUDE & VERTICAL VELOCITY SYSTEM
$H_O-H_A=H$
SLANT RANGE & ELEVATION ANGLE SYSTEM
R
ΔR
HORIZONTAL RANGE SYSTEM
V_R
R
Δμ
AZIMUTH SYSTEM
V_μ
θ
P_S
P_V
AIR SPEED COMPUTER
TEMPERATURE
V_A
θ_R
μ
R
RANGE & TRUE BEARING RATES SYSTEM
RV_W
μV_W
V_A
θ
R_W
μ
GROUND SPEED CONVERTER & RELATIVE COURSE SOLVER
θ

Figure 12–8.—Tracking data computer functional block diagram.

peatedly throughout the remainder of the discussion, should not be interpreted as referring to the three systems of the bomb director mentioned previously. These divisions are based on the functions of each system and are shown in figure 12–8, a functional block diagram of the tracking data computer. The interdependence of some of the systems should be noted.

The systems and their functions are shown in table 12–1. In addition to the seven systems, it should be noted that a constant speed motor and gear shift system is included. Its function is to supply rotary motion to various assemblies in the computer either in the form of power or as a time base in the mechanical computing elements.

Horizontal range system.—As pointed out previously, the purpose of this system is to provide a continuous solution for horizontal range *R*. Before considering the mechanisms used in this solution, we will discuss the mathematical operations concerned.

If, at the beginning of the bombing run, the initial hori-

Table 12-1.—Functional systems.

System	Function
Horizontal range	Supply the bomb director with horizontal range R at all times.
Altitude and vertical velocity	Compute altitude of aircraft above aim point H, above target $H_a - H_t$, and vertical velocity of aircraft V_H.
Slant range and elevation angle	Develop slant range r and elevation angle ϕ from computed values of R and H.
Azimuth	Develop true bearing μ and relative bearing θ_R.
Airspeed	Compute true airspeed V_A of the aircraft.
Range and true bearing rates	Provide correct range rate V_R and azimuth rate $V\mu$.
Groundspeed converter and relative course solver	Convert computed groundspeed V_G to usable information and develop relative course η_R.

zontal range R_O is known, R may be found any time during the bombing run by subtracting the horizontal distance traveled after the start of the run from R_O. Since V_R is fed to the system, the simplest way of finding distance traveled is by finding the $\int V_R \, dt$. The final operation is the subtraction of one quantity from the other and may be written as follows:

$$R = R_o - \int V_R \, dt$$

This solution is accurate only if the initial value of R_O is correct. However, the computer also provides a means of compensating for any error in R_O. A quantity ΔR is added to the equation as follows:

$$\mathrm{R} = (R_o + \Delta R) - \int V_R \, dt$$

where ΔR is positive when R_o falls short of the aim point and negative when R_O falls beyond the aim point.

We shall now consider the operation of the horizontal range system. The main components of the system are the

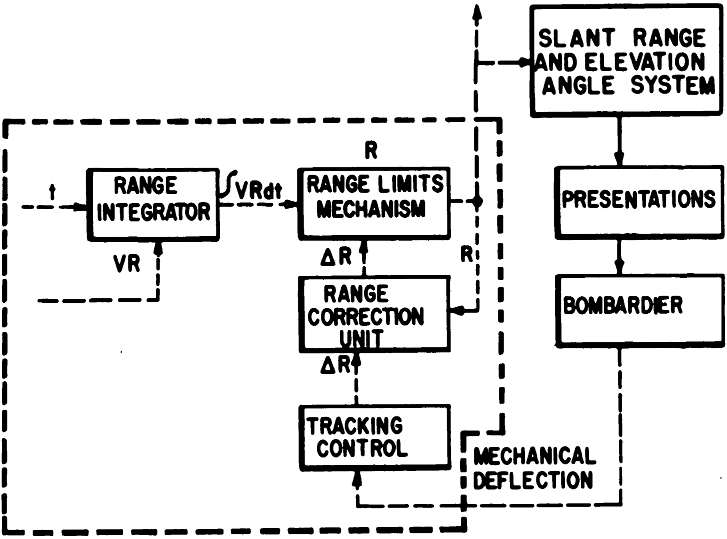


Figure 12–9.—Horizontal range system block diagram.

operator's tracking control, range correction unit, range limits mechanism, and range integrator. (See fig. 12–9.)

The OPERATOR'S TRACKING CONTROL permits the operator to make the necessary range correction (ΔR) to place the cross hairs on the aim point. The operator, by moving the tracking control either forward or backward, actuates a switch which energizes a range correction motor. Note: The direction of rotation of the motor is determined by the direction of handle movement. This motor continues to run at a constant speed in the same direction as long as the control handle is held in the displaced position.

The RANGE CORRECTION UNIT contains the range correction motor which converts the electrical signal from the tracking control into mechanical rotation. The direction of rotation and the duration of its operation are determined by the amount and direction of the ΔR correction. The output of the unit is a mechanical shaft rotation (ΔR) that is fed to the range limits mechanism.

The RANGE INTEGRATOR provides a means of determining distance or range traveled in a specified time. Its inputs are range rate V_R and t. The unit consists of a mechanical ball-disk-roller type integrator and its input and output shafts. (NOTE: This type integrator was discussed in detail in chapter 9 of this course.) The input t is supplied by a constant speed motor and is used to drive the integrator disk at a constant speed. The quantity V_R positions the ball carriage with the output from the roller being proportional to the $\int V_R\,dt$.

The RANGE LIMITS MECHANISM is a device for combining $R_O \pm \Delta R$ and $\int V_R\,dt$. It consists of a simple mechanical differential with the inputs applied as shown in figure 12–10. The initial range R_O is represented by the position of the lower end gear a. The quantity ΔR is added to this

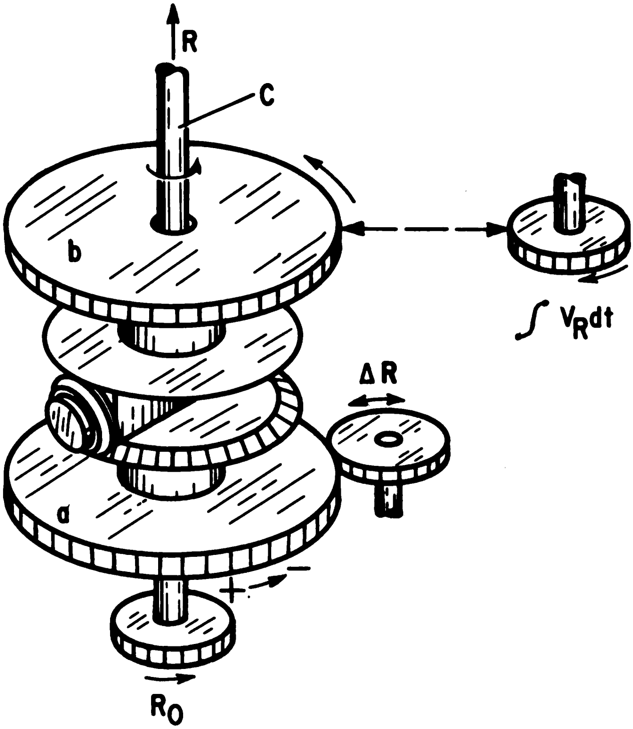


Figure 12–10.—Range limits differential.

position by the spur gear assembly driven by the output from the range correction unit.

The quantity $\int V_R\,dt$ drives the differential end gear *b* through a spur gear assembly. The differential sums the quantity $\int V_R\,dt$ and $R_O \pm \Delta R$ and produces an output proportional to $R_O \pm \Delta R - \int V_R\,dt$. The output *R* is represented by the position of the spider shaft *c* and is supplied by mechanical linkage to other units of the director.

THE ALTITUDE AND VERTICAL VELOCITY SYSTEM.—This system computes the altitude of the aircraft above sea level H_O, the altitude of the aircraft above the aim point $H_O - H_A$, altitude of the aircraft above the target $H_O - H_T$, and the vertical velocity of the aircraft V_H. The quantity $H_O - H_A$ is used by the tracking data computer in determining calculated slant range. The quantities $H_O - H_T$ and V_H are fed to the release point data computer for the computation of time of fall t_f and trail T'.

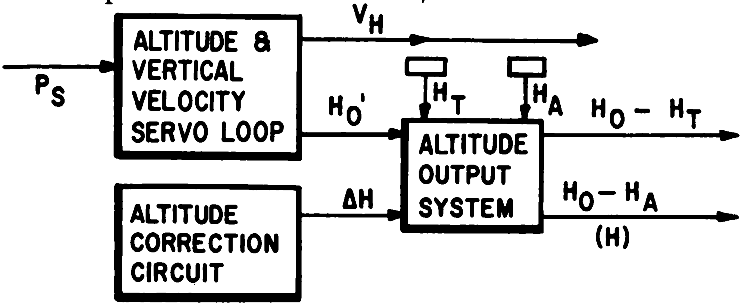


Figure 12–11.—Block diagram of the altitude and vertical velocity system.

The system is composed of an altitude and vertical velocity servo loop, altitude correction circuit, and an altitude output system. A block diagram showing the input and output data of each unit of the system is shown in figure 12–11.

The ALTITUDE AND VERTICAL VELOCITY SERVO LOOP consists of a pressure chamber with a diaphragm assembly, servo clutches, vertical velocity integrator, and altitude cam. The servo loop is controlled by a pressure sensitive mechanism in an airtight chamber as shown in figure 12–12.

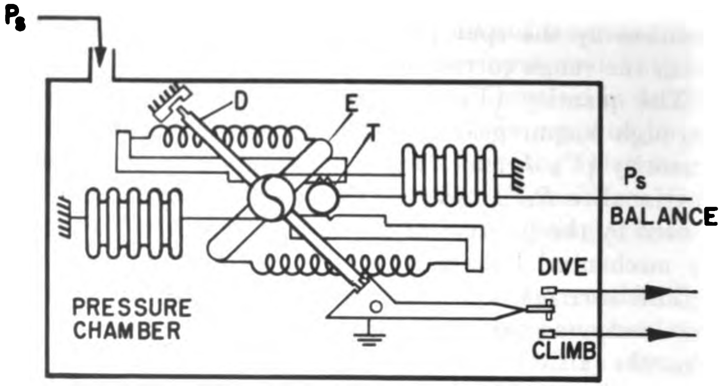


Figure 12–12.—Pressure chamber and mechanism.

Static pressure P_S is constantly admitted to the pressure chamber and surrounds the diaphragms which sense any change in pressure due to a change in altitude. The diaphragms are connected by a metal strap which passes through and is connected to the shaft of arm *D*. Arm *E* is also attached to the same shaft. Each end of arm *E* has a calibrated spring attached to it, the opposite end of which is attached to its respective rail. The position of the rails is controlled simultaneously by gear *T*, which receives its input from the altitude cam outside of the pressure chamber.

When the mechanism is in a balanced condition, torque on the shaft due to the diaphragms equals the torque set up by the springs. A change in P_S creates an unbalance between the diaphragms and the springs. Consequently arm *D* rotates, closing the dive or climb contacts as required. This action results in either the climb or dive clutch being engaged in accordance with the change in P_S. Thus, V_H data, proportional to the detected change in pressure, is mechanically fed to the V_H integrator as shown in figure 12–13.

Integrating the equation $\int V_H\, dt$ should produce an output that is proportional to the change in altitude of the aircraft. For purpose of explanation we shall refer to this change in altitude as $\Delta H_O'$. Referring to figure 12–13, it

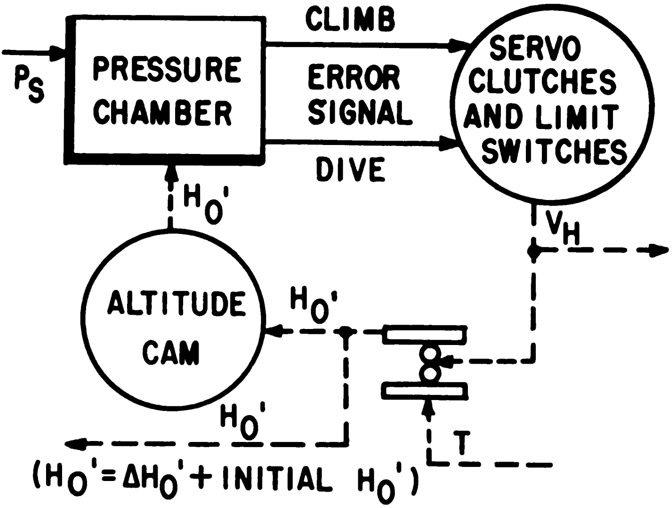

CLIMB
P_S
PRESSURE CHAMBER
ERROR SIGNAL
SERVO CLUTCHES AND LIMIT SWITCHES
DIVE
H_0'
V_H
ALTITUDE CAM
H_0'
H_0'
T
$(H_0' = \Delta H_0' + \text{INITIAL } H_0')$

Figure 12–13.—Altitude and vertical velocity servo loop.

should be obvious that the output of the integrator will cause the roller shaft to rotate an amount proportional to $\Delta H_0'$. However, this quantity $\Delta H_0'$ is combined with the quantity H_0' that is represented by the starting position of the roller shaft. Therefore, the output of the integrator is $\Delta H_0'$ + INITIAL or previous value of H_0' which equals H_0'.

The quantity H_0' represented by the rotation of the integrator roller output shaft is transmitted to the output system and to an altitude cam. The cam, which is designed to compensate for the nonlinearity of the atmosphere, drives gear T in the pressure chamber shown in figure 12–12. The action of the gear is to bring about a balanced condition between the diaphragms and the calibrated springs. This is done by the gear positioning the rails to cancel the force, causing the unbalanced condition and thus opening the DIVE-CLIMB switch. It must be remembered that the balanced condition is restored only after the quantity H_0' has been corrected to the new pressure altitude of the aircraft.

The OUTPUT SYSTEM which consists of three differentials s shown in figure 12–14. The correction differential re-

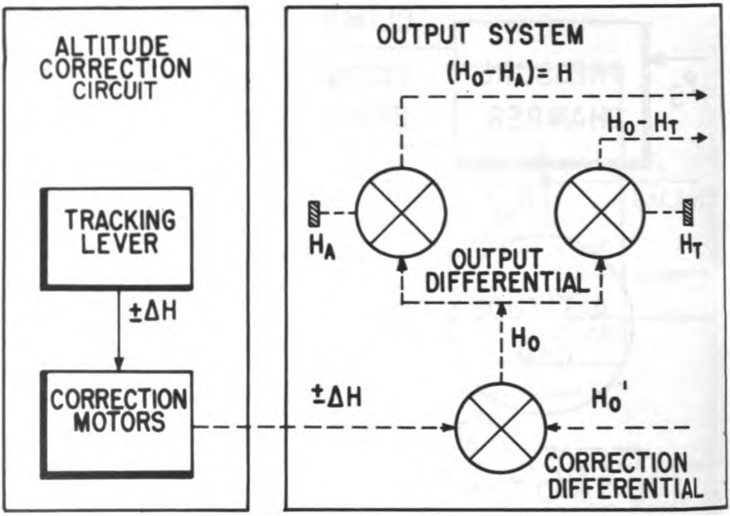


Figure 12–14.—Altitude correction circuit and output system.

ceives H_O' and combines it with the output of the altitude correction circuit ΔH. (NOTE: The correction circuit will be discussed in a later paragraph.) The output of the correction differential, a shaft rotation proportional to H_O the corrected altitude of the aircraft, is coupled to parallel output differentials. The quantity H_A (altitude of the aim point) is subtracted from H_O in one differential to give an output of $H_O - H_A$ equal to H which is fed to the slant range and elevation angle system.

The other differential subtracts H_T (altitude of the target) from H_O to give an output of $H_O - H_T$ which is the altitude of the aircraft above the target. This information is transmitted to the release point data computer.

The ALTITUDE CORRECTION CIRCUIT provides a means of correcting the computed altitude for any error due to variations in atmospheric pressure or other inaccuracies that may affect the output of the altitude computer. This is accomplished by presenting the quantity H on a radarscope where it can be compared with the quantity r as measured by the radar from the aircraft to the ground directly below it. Should the two quantities differ, the tracking lever would be positioned to cause the correction motor to run, generating an output ΔH which is fed to the correction differential. This output is continued until the quantities H and r are equal. This correction also corrects the output $H_O - H_T$ and $H_O - H_A$. NOTE: The computer must be in the ALTITUDE SET mode of operation for this correction.

SLANT RANGE AND ELEVATION ANGLE SYSTEM.—The solution of the bombing problem requires that horizontal range and horizontal range rate be determined from data generated by aim point tracking. However, neither the radar nor the optical system can measure these values directly. The radar measures slant range and the optical system measures the elevation angle. Therefore, when utilizing radar tracking, the system must compute slant range for comparison by the operator with actual slant range as determined by the radar. When utilizing optical tracking, the elevation angle must be computed so that it may be compared with the measured elevation angle.

The slant range and elevation angle system determines slant range r and elevation angle ϕ from inputs of horizontal range R and altitude above the aim point H. As shown in figure 12–15, it can be seen how the formulas for r and ϕ are determined. Slant range is computed from the formula

$$r = \sqrt{H^2 + R^2} \qquad (1)$$

By squaring both sides of the equation we get

$$r^2 = H^2 + R^2 \qquad (2)$$

or

$$R^2 = r^2 - H^2 \qquad (3)$$

which may be written as $R \cdot R = (r - H)\ (r + H)$. (4)

By multiplying both sides of the equation by $\frac{1}{R\,(r-H)}$,

we now have

$$\frac{R}{r-H} = \frac{r+H}{R}. \qquad (5)$$

The elevation angle ϕ is computed from the formula

$$\phi = \arc \tan \frac{R}{H}.$$

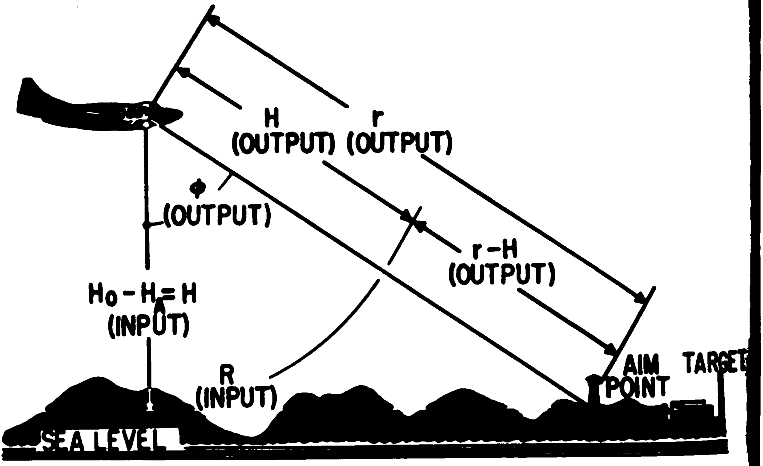


Figure 12–15.—Slant range and elevation angle problem.

The slant range and elevation angle system will be discussed in two parts—the slant range servo loop and the elevation angle servo loop.

The quantity R mechanically positions the arms of potentiometers R_3 and R_4 making their resistance proportional to this input. (See fig. 12–16.) The quantity H positions the arm of potentiometer R_5, giving an electrical voltage output that is proportional to H. The mechanical input H is also fed to a mechanical multiplier whose output is a rotation proportional to $2H$. Output $2H$ is fed to differential A where it is summed with the quantity $r-H$ giving an output of $r+H$. NOTE: It should be remembered that in any servo loop, quantities from the last computation will remain until new data is received necessitating a change in the output. The quantity $r+H$ is used to position the arm of potentiometer R_1, making its resistance proportional to $r+H$. The resistance of R_2 is made proportional to the quantity $r-H$ in a similar manner as shown in figure 12–16.

It should be remembered that the output of a servo loop of this type is dependent upon a balanced condition existing in the bridge circuit. Therefore, as shown in figure

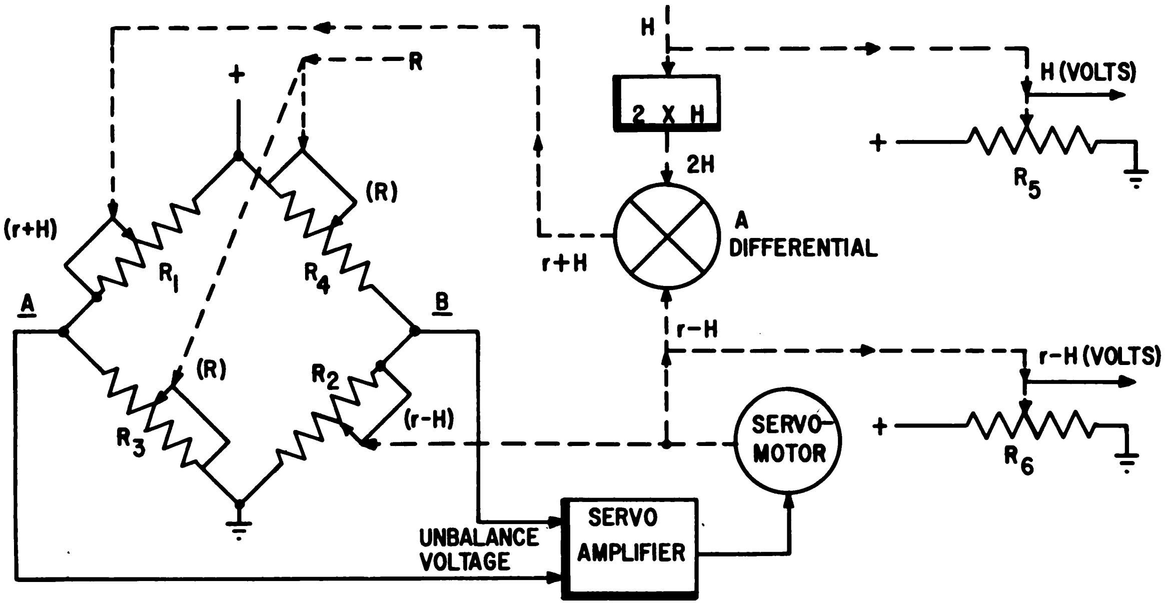


Figure 12-16.—Slant range servo loop.

12–16, with the bridge circuit in a balanced condition, the following relationship exists:

$$\frac{R_4}{R_2}=\frac{R_1}{R_3}.$$

Since the setting of each potentiometer is determined as previously discussed, we may then write the following expression

$$\frac{R}{r-H}=\frac{r+H}{R}.$$

It should be recalled that the above equation is the same as that given in formula (5).

Thus, we have discussed the bridge circuit with its various inputs which acts as an error detector of the servo loop. Let us now consider the remainder of the servo loop. The output of the bridge, which is a voltage indicative of the direction and amplitude of any unbalanced condition, is taken between points A and B. This output is fed to the servo amplifier where it is amplified and used to drive the servomotor in the direction that will cancel the unbalanced condition.

To illustrate the operation of the loop, let us consider a reduction in the quantity R due to forward motion of the aircraft. The resistance of R_3 and R_4 would be reduced, causing point B to become positive in respect to A. This voltage, when amplified, would cause the servomotor to rotate in a direction reducing the quantity $r-H$ and in turn reducing the resistance of R_2. Since the servomotor shaft is mechanically coupled to R_6 and the differential A, the change in output will be reflected in both R_1 and R_6. The servomotor will continue to operate until a balanced condition has been restored to the bridge, thus reducing the output of the loop to zero.

As previously mentioned, R_6 is positioned by the quantity $r-H$. This potentiometer provides the second output, an electrical voltage that is proportional to $r-H$.

It should be remembered that the servo loop set out to solve for r. However, the outputs discussed previously have been voltages proportional to $r-H$ and H. These voltages are combined in a later stage to produce the desired result r. This solution is illustrated graphically in figure 12–15.

The ELEVATION ANGLE SERVO LOOP computes the elevation angle ϕ from its inputs of R and H. Referring to figure 12—15, it should be noted that

$$\phi = \tan^{-1}\frac{R}{H}$$

or

$$\tan\phi = \frac{R}{H}.$$

The servo loop utilizes a balanced bridge circuit as an error detector, a servo amplifier, and servomotor. The output of the loop, the angle ϕ, is fed back to the balanced bridge thereby completing the servo loop. (See fig. 12–17.)

The balanced bridge consists of three potentiometers as follows:

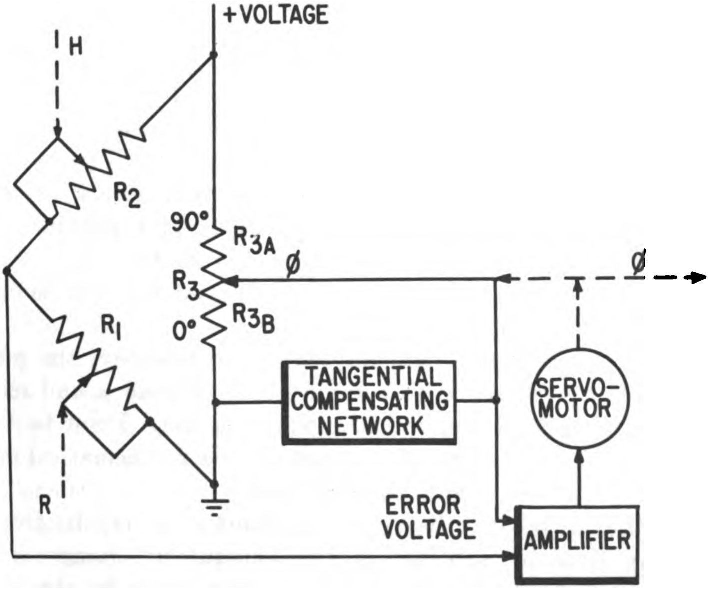


Figure 12–17.—Elevation angle servo loop.

R^1 Resistance is controlled by and made proportional to R.

R_2 Resistance is controlled by and proportional to H.

R_3 This potentiometer is controlled by feedback ϕ from the output of servo loop.

As in the bridge circuits discussed previously, the bridge is said to be balanced when the following relationship exists:

$$\frac{R_1}{R_2}=\frac{R_3B}{R_3A}$$

Since R_1 and R_2 are controlled by R and H respectively, the following expression may be written:

$$\frac{R_3B}{R_3A}=\frac{R}{H}$$

The desired output of servo loop is an angle ϕ whose tangent equals $\frac{R}{H}$ That is, the ratio of R_3B to R_3A would be equal to the tangent of the angle ϕ. If R_3 is a linear wound potentiometer, the output of the loop would be correct for outputs 0, 45, and 90 degrees. However, for outputs between these points, the shaft could be in error as much as three degrees. (NOTE: A comparison of R_3B/R_3A to the tangent table in a book of tables will prove this inaccuracy.) Therefore, a compensating network is utilized to make the necessary corrections and produce the correct output. (NOTE: The operation of this servo loop is similar to the slant range servo loop and will not be discussed further at this time.)

AZIMUTH SYSTEM.—As pointed out previously, the purpose of this system is to compute true bearing μ and relative bearing θ_R throughout the bombing run. Prior to discussing the mechanics of the system, the mathematical operations concerned will be discussed.

If the initial true bearing μ_o is known, μ may be found at any time by subtracting the amount of change in μ from μ_o. (See fig. 12–3.) This quantity may be obtained essentially by integrating the rate of change of azimuth $V\mu$. However, range R must also be considered because μ

will vary as the range to the target decreases. Thus, $V\mu$ is integrated in respect to a quantity, time divided by range, or $\overline{\frac{dt}{R}}$, and produces an output of $\int V\mu \frac{dt}{R}$. Thus, the final operation to obtain μ is to subtract one quantity from the other as indicated in the following equation:

$$\mu = \mu_o - \int V\mu \frac{dt}{R}$$

This solution is accurate only if the initial value of μ_o is correct. However, means are provided to compensate for any error in μ_o. A quantity $\Delta\mu$ is added to the equation as follows:

$$\mu = (\mu_o \pm \Delta\mu) - \int V\mu \frac{dt}{R}$$

where $\Delta\mu$ is positive when the line of sight appears to the left of the aim point on the radarscope and negative when the line of sight appears to the right of the aim point.

As shown in figure 12–3, the aircraft's heading and the bearing of the aim point are given relative to true north. The angular relationship of the aircraft's heading and the aim point $\theta - \mu$ must also be known for calculation of groundspeed and other data used by the release point data computer. Therefore, by definition the clockwise angle from the aim point to the aircraft's heading is θ_R and may be written as follows:

$$\theta_R = \theta - \mu$$

The azimuth system consists essentially of the tracking control, azimuth correction unit, range reciprocal integrator, azimuth integrator, μ differential, and the heading system. (See fig. 12–18.)

The RANGE RECIPROCAL INTEGRATOR will be discussed first since it involves a different application of the ball-disk-roller mechanical integrator. Its appearance and mechanical operation are identical to those discussed previously in this course. In those cases, an input, varying in amplitude, was effectively multiplied by time. Time was represented by disk rotation, and the variable input by the distance the

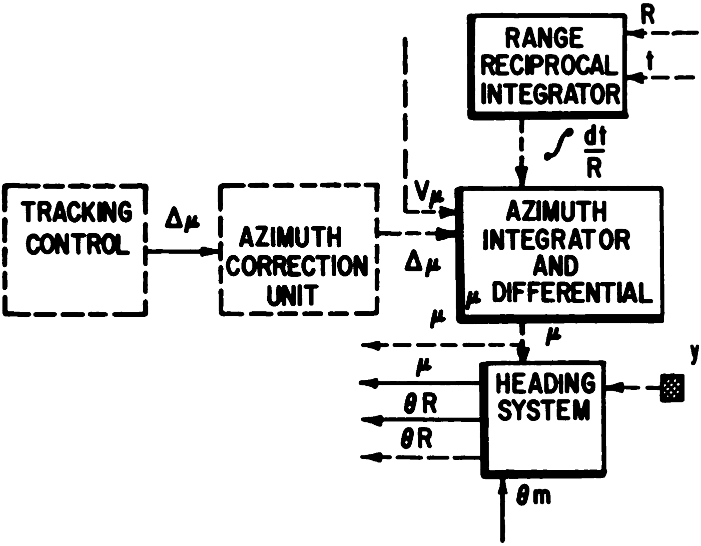


Figure 12–18.—Block diagram of the azimuth system.

ball carriage was displaced from the center of the disk. The output was taken from the roller.

In the reciprocal integrator, the input time is applied to the roller and the quantity R positions the ball carriage. Therefore, the output taken from the disk is equal to the $\int \frac{dt}{R}$. (This is effectively using a multiplying device to divide.) The output is proportional to $\frac{t}{R}$.

The AZIMUTH INTEGRATOR disk is driven by the output of the reciprocal integrator $\int \frac{dt}{\mathrm{R}}$. The ball carriage is positioned by the azimuth rate $V\mu$. Thus, the output taken from the roller of the integrator is $\int V\mu \frac{dt}{R}$. This quantity is fed to the μ differential.

The AZIMUTH CORRECTION UNIT operates in a manner similar to the range correction unit discussed previously in this chapter. Its function is to introduce $\Delta\mu$ for the purpose of correcting μ_o in the event this quantity is in error as previously stated in this section. Thus, the quantity $\mu_o + \Delta\mu$ is developed. It is assumed that some value of μ_o is already in the system from a previous solution. Therefore, only the quantity $\Delta\mu$ is indicated entering the μ differential. The quantity μ_o, corrected by $\Delta\mu$, is then combined with $\int V\mu \frac{dt}{R}$ in the μ differential, producing an output of μ.

The HEADING SYSTEM (fig. 12–19) performs two functions. From the mechanical inputs of μ and y and the electrical input of θ_m, the heading system produces a mechanical output θ_R and electrical outputs of μ and θ_R.

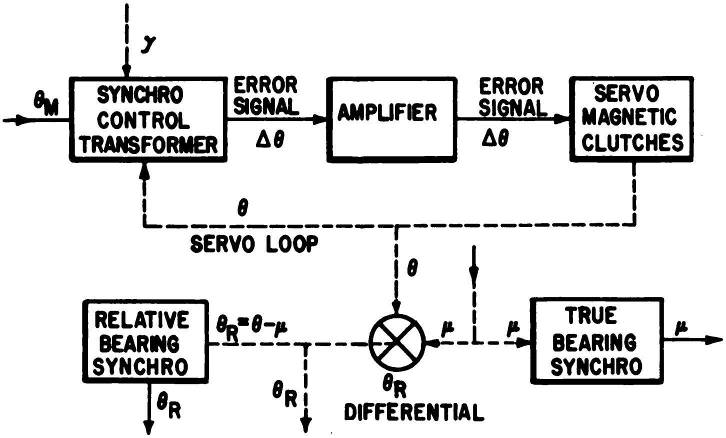


Figure 12–19.—Block diagram of the heading system.

A signal representing magnetic heading of the aircraft θ_m is received from the stabilizing system by the synchro control transformer. Magnetic variation y is introduced as a hand input and rotates the stator windings and housing assembly by an amount equal to the magnetic variation. In this manner θ_m is corrected to θ, the true heading of the aircraft.

When the aircraft changes its true heading θ by any amount, an error signal denoted by $\Delta\theta$ is developed in the synchro control transformer. This error signal is amplified and used by a clutch assembly which drives the θ_R differential to a new position representing the correct true heading of the aircraft. This value of θ is also fed back to null out the error in the synchro control transformer. The θ_R differential also receives μ, which combines with θ to produce θ_R, relative bearing. Mechanical θ_R is converted to an electrical signal by the relative bearing synchro, and mechanical μ is converted to an electrical signal by the true bearing synchro.

THE AIRSPEED SYSTEM.—The airspeed system calculates airspeed from static and pitot atmospheric pressures and stagnation temperature. The output of the system V_A is supplied the range and true bearing rate system, and the release point data computer.

The airspeed system consists essentially of a Wheatstone bridge, which is controlled by an electrical servo loop and a mechanical servo loop. To simplify the discussion, we shall consider the mechanical servo loop first which is, for

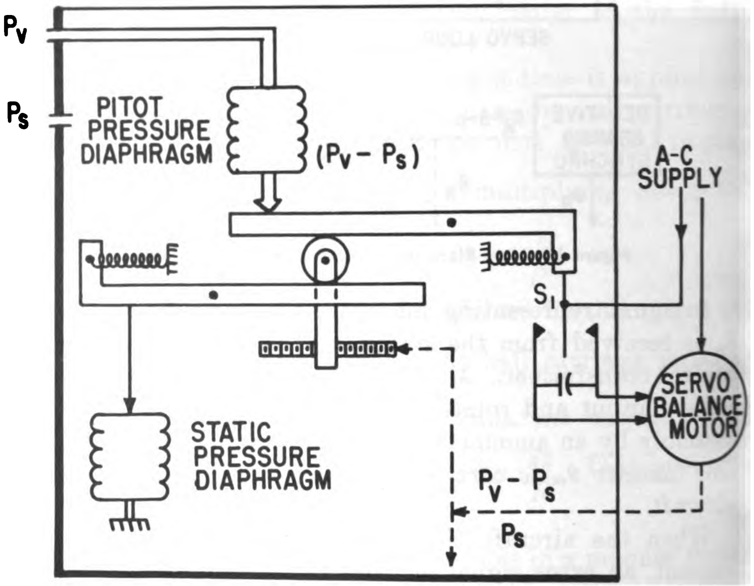


Figure 12–20.—Mechanical servo loop.

the most part, enclosed in a chamber. It consists of two diaphragms, a rail and roller assembly, a lead screw, and a drive motor with its associated circuitry. Figure 12–20 illustrates the mechanical servo loop and should be studied in detail.

It should be noted that static air pressure P_S is admitted to the chamber and surrounds both diaphragms. The displacement of the static pressure diaphragm will be inversely proportional to the static pressure or directly proportional to the altitude. The pitot pressure diaphragm has pitot pressure applied to its inner surface in addition to the static pressure. The two pressures are opposing; thus the displacement of this diaphragm is directly proportional to $P_V - P_S$. It should be noted that the pitot pressure diaphragm is mechanically attached to the upper rail, and the static pressure diaphragm determines the position of the lower rail.

Any change in either P_V or P_S (or both) will cause the rails to tilt and close switch S_1 in accordance with the unbalance. The servomotor is then energized and drives the lead screw in the direction necessary to bring the rails back to a balanced condition. The servomotor also transmits its shaft position to a potentiometer in the Wheatstone bridge, causing an unbalance and a corresponding change in the output of the system. (See fig. 12–21.)

The Wheatstone bridge consists of a linear potentiometer R_1, a resistive temperature element R_2, and a square law potentiometer R_3. As shown in figure 12–21, the output of the mechanical servo loop positions the wiper arm of R_1, making it indicative of the quantity $\frac{P_V - P_S}{P_S}$. NOTE: Corrected airspeed is computed from the formula

$$V_A^2 = 87^2(T_S)\left[1 - \left(\frac{P_S}{P_V}\right)^{\frac{1}{3.5}}\right].$$

However, the instrumentation of this formula is beyond the scope of this course and will not be discussed.

The wiper arm of potentiometer R_3 is positioned by the output from the electrical servo loop, making its position

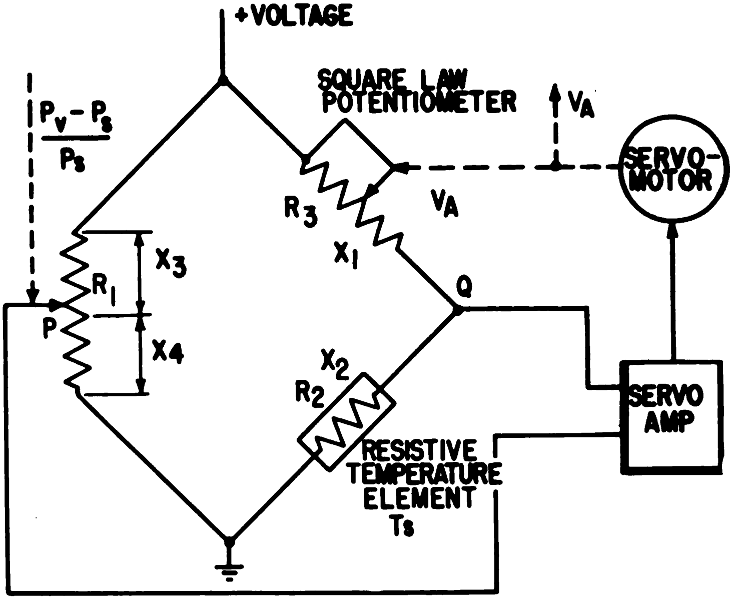


Figure 12–21.—Wheatstone bridge and electrical servo loop.

indicative of the quantity V_A. However, the resistance of R_3 will be proportional to V_A^2 since R_3 is a square law potentiometer.

When the bridge is in a balanced condition, the following condition exists:

$$\frac{X_1}{X_2} = \frac{X_3}{X_4}$$

Therefore, the voltage between points P and Q will be zero and there will be no amplifier output to the servomotor.

When the bridge circuit becomes unbalanced due to a change in P_V, P_S, or T_S, a voltage will appear across the bridge which is fed to the amplifier. The amplifier's output will cause the servomotor to rotate in the direction necessary to restore the balanced condition, thus correcting V_A.

The output of the airspeed system is a shaft rotation and is fed to other parts of the computer as discussed previously.

Range and true bearing rate system.—Preceding sec-

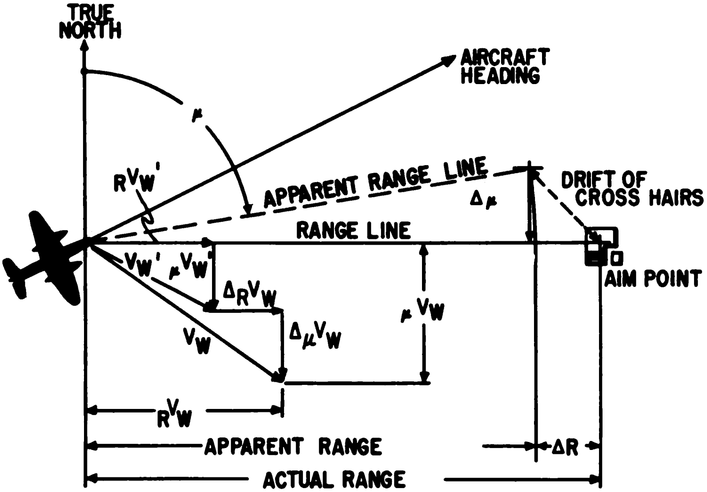


Figure 12–22.—Vector analysis of wind rate corrections.

tions of this chapter describe how range and azimuth values are computed and how the tracking control may be used to position the crosslines on the aim point. However, the computer must provide some means of continuously correcting both R and μ as the aircraft progresses in its bombing run. This is done by determining the rate of change of R and μ which is used as a correction rate for their respective quantities.

The rate of change of R and μ may be resolved from the groundspeed of the aircraft. However, before considering how V_G is used to compute these rates, we shall discuss briefly the computation of V_G. Groundspeed is the vectorial sum of true airspeed V_A and wind V_W. Initial values of wind, based on predictions, are manually set into the equipment. However, wind predictions are very inaccurate, and it is necessary that frequent wind corrections be made by the operator. The manner in which wind corrections are made will be explained in the discussion that follows.

Figure 12–22 illustrates a drift of the crossline from the aim point due to incorrectly computed values of wind velocities. In the lower left-hand portion of the figure, the true wind velocity is shown by the vector V_W. However, the value of wind previously set up at the wind resolver, depicted here as V_W', is not the correct value. Therefore, the crosslines drift off the aim point at a rate which is the difference between the apparent wind velocity V_W', and true wind velocity V_W.

The wind velocities are actually computed in terms of rectangular coordinates rather than polar coordinates. Therefore, the wind velocity V_W' is expressed at the wind resolver in terms of two components, range wind ${}_RV_W'$ and cross wind $\mu V_W'$. It is obvious from the diagram that the range wind component is plotted along the range line while the cross wind component is plotted perpendicular to the range line. Therefore, in making a wind correction, the range and azimuth correction unit produces two outputs $\Delta_R V_W$ and $\Delta\mu V_W$, corresponding to a change in range wind and a change in cross wind, respectively. These two outputs are applied to the wind resolver unit, where the $\Delta_R V_W$ value is added algebraically to the ${}_RV_W'$ value, and $\Delta\mu V_W$ and $\mu V_W'$ values are added in the same manner.

In making the rate correction, the crosslines must be displaced by an amount equal to (but opposite in direction to) the distance they have drifted off the aim point in a given time. The $\Delta\mu V_W$ and $\Delta_R V_W$ outputs of the range and azimuth correction unit represent the difference between V_W' and V_W (in terms of rectangular coordinates). When these values are added to the existing values in the wind resolver unit, the true wind values ${}_RV_W$ and μV_W are obtained, thus correcting V_W and V_G. The corrected value of V_G results in a correction to V_μ and V_R. If the above rate corrections are made correctly, the crosslines will now remain on the aim point.

The range and true bearing rate system (fig. 12–23) consists primarily of the rate correction circuit, the wind resolver, the wind vector solver, and the groundspeed resolver.

The RATE CORRECTION CIRCUIT computes changes in wind rates which are fed to the wind resolver. The circuit con-

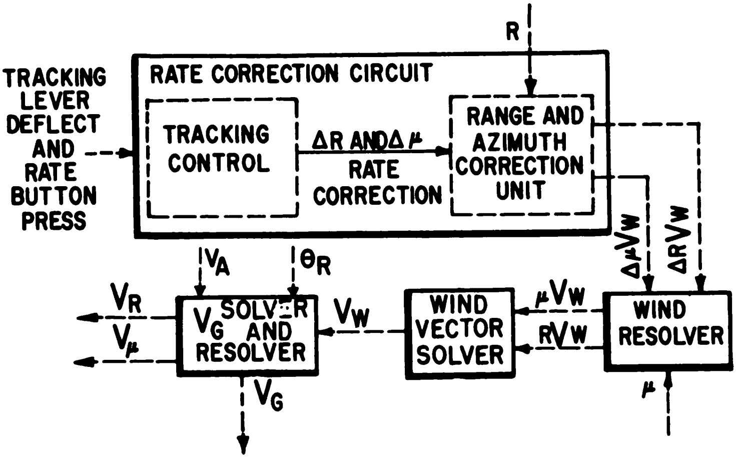


Figure 12–23.—Block diagram, range and true bearing rate system.

sists of the tracking control and a portion of the correction unit. It should be recalled that the tracking control was used to make range and azimuth displacement corrections. In the rate mode of operation, it performs an additional function by supplying the rate correction circuit the necessary data for computation of wind rate corrections. The quantities $\Delta\mu$ and Δ_R are fed directly to the azimuth correction and range displacement integrators, respectively. This is illustrated in the block diagram of the rate portion of the range and azimuth correction unit shown in figure 12–24.

The value of $\Delta\mu$ generated by displacing the tracking control in azimuth is an angular (nonlinear) quantity. However, computer devices for determining rates from linear quantities are much simpler. Therefore, the angular quantity is fed to an azimuth correction integrator whose function is to produce a linear output that is proportional to $\Delta\mu$. This integration is illustrated in figure 12–25.

The quantity $\Delta\mu$ drives the disk of the azimuth correction integrator and *R* positions the ball carriage. The output is taken from the roller and drives the roller of the azimuth rate integrator through a boost differential.

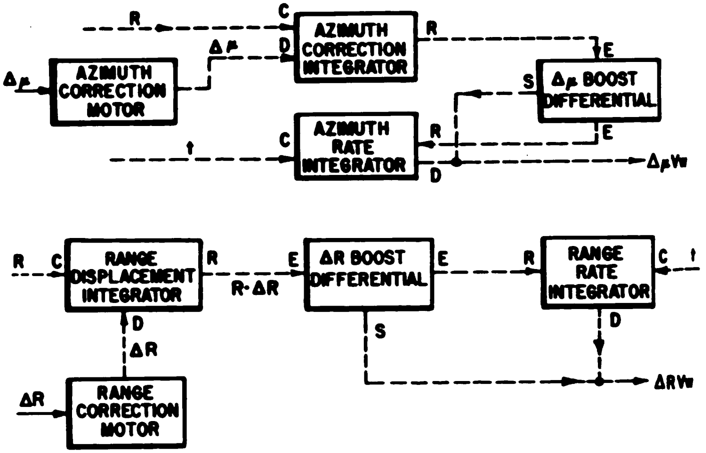


Figure 12–24.—Block diagram of the rate portion of the range and azimuth correction unit.

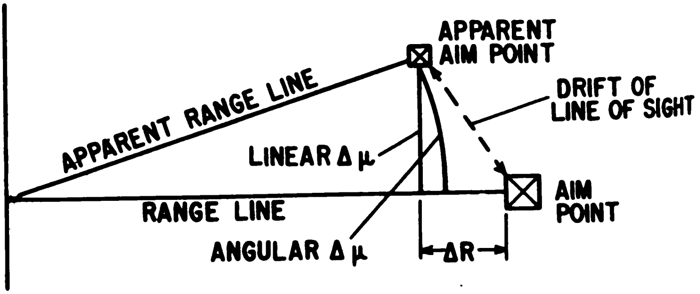


Figure 12–25.—Conversion of angular $\Delta\mu$ to linear $\Delta\mu$.

(NOTE: An integrator with an input applied to the roller is a dividing integrator.) The ball carriage is positioned by time; thus, the output $\int \frac{R\,\Delta\mu}{t\mu}$ is taken from the disk shaft. This output may be more simply expressed as $\Delta\mu V_W$ which is the azimuth wind rate correction.

When the tracking control is actuated fore and aft, the range correction motor drives the disk of the range displacement integrator by an amount proportional to ΔR. The ball carriage is positioned by R; thus, the output from the roller is $R\ (\Delta R)$. This quantity drives the roller of the range rate integrator with a power boost from a boost differential. Time positions the ball carriage; thus, the output from the disk of the range rate integrator is $\int \frac{R\,(\Delta R)}{t_R}$. This quantity may be more simply expressed as range wind rate correction $\Delta_R V_W$ previously discussed in this section.

The WIND RESOLVER functions to solve continuously for the range and azimuth components of the wind vector. The wind resolver consists essentially of two integrators and two differentials as shown in figure 12–26. Observe particularly the mechanical crossover network, noting that the output of the cross wind integrator and differential is used to position the ball carriage of the range integrator, and that the output of the range integrator and differential is used in a similar manner in the cross wind integrator.

The disk of both integrators is driven by μ, a quantity that is continuously changing as the aircraft proceeds along its course. NOTE: The mathematical equations for this circuit are beyond the scope of the course and will not be discussed. Referring to figure 12–26, the output of the cross wind integrator μV_W is combined with previous val-

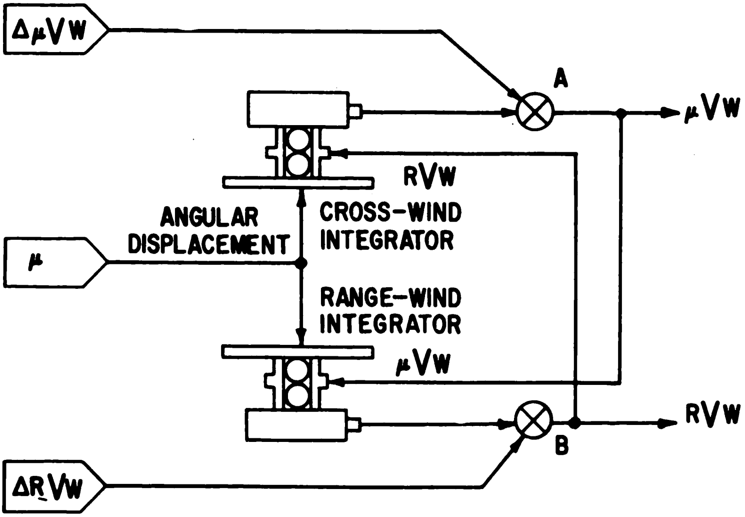


Figure 12–26.—Wind resolver.

ues of ${}_{\mu}V_W$ to give a corrected value of cross wind. A corrected value of range wind is also computed in a similar manner.

The WIND VECTOR SOLVER functions to vectorially combine the corrected values of ${}_{\mu}V_W$ and ${}_{R}V_W$ to give wind velocity V_W. The wind velocity vector is then combined with the true airspeed vector to give groundspeed.

The device for vectorially combining ${}_{\mu}V_W$ and ${}_{R}V_W$ is shown in figure 12–27. The cross wind frame is displaced in a direction perpendicular to the line of sight by the input gear which is driven by a mechanical input of ${}_{\mu}V_W$. The range wind frame is similarly positioned by ${}_{R}V_W$; thus, the resultant movement of the V_W shaft is proportional to the magnitude and direction of V_W. The V_W shaft forms the center line of the groundspeed solver and constitutes an input of V_W. Since V_W is required by no other part of the computer, this is the only output of the wind vector solver.

The GROUNDSPEED SOLVER AND RESOLVER combines the corrected wind velocity vector with true airspeed to give an

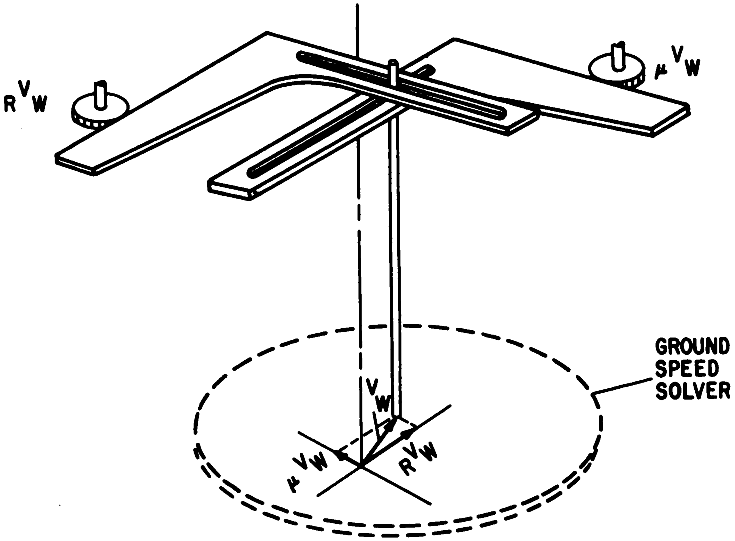


Figure 12–27.—Wind vector solver.

output proportional to groundspeed. This device is shown in the upper portion of figure 12–28. The inputs to the solver are wind velocity and direction (position of the center shaft as discussed in the previous paragraph) and airspeed amplitude and direction. Referring to figure 12–28, mechanical V_A drives the magnitude cam which positions the V_G pin a distance proportional to the value of V_A. The V_A vector is then positioned as θ_R drives the angular posi-

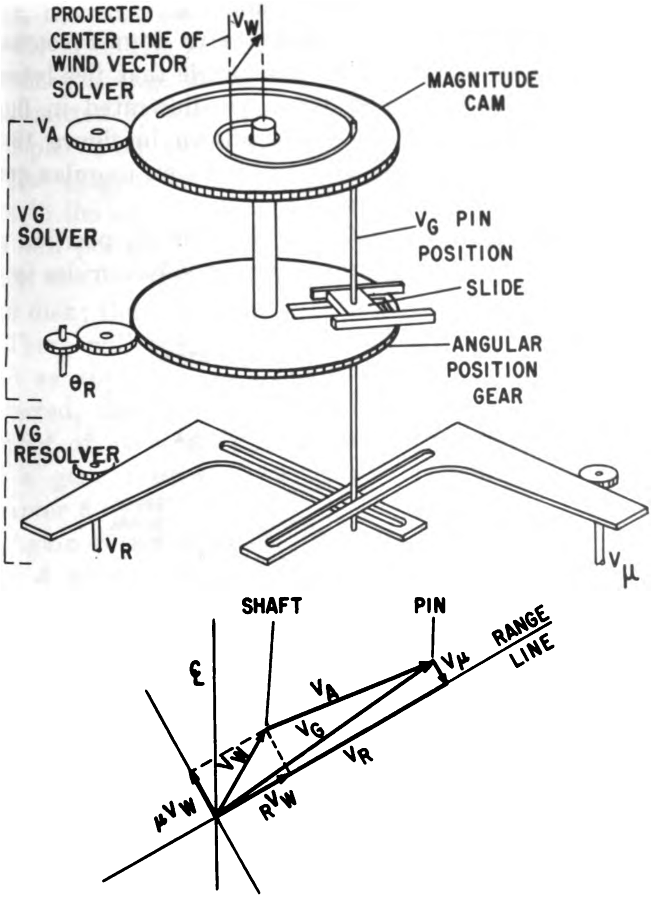


Figure 12–28.—V_G solver and resolver.

tion gear. It should be remembered that the V_A vector is positioned in relation to the head of the V_W vector and that groundspeed is measured from the projected center line of the wind vector solver to the V_G pin. The relationship of these vectors is extremely important and should be thoroughly understood before going further in the computer.

As the V_G pin is positioned it is simultaneously positioning two racks, the outputs of which are the rectangular components of V_G. They are V_μ and V_R.

GROUNDSPEED CONVERTER AND RELATIVE COURSE SOLVER.—Relative course, η_R is the clockwise angle that lies between the range line and ground track as illustrated in figure 12–3. The relative course solver, shown in figure 12–29, not only solves for η_R but also produces an angular quantity γ representing nonlinear V_G.

Referring to figure 12–29, note that the V_G position pin, which extends from the airspeed vector solver, rides in the

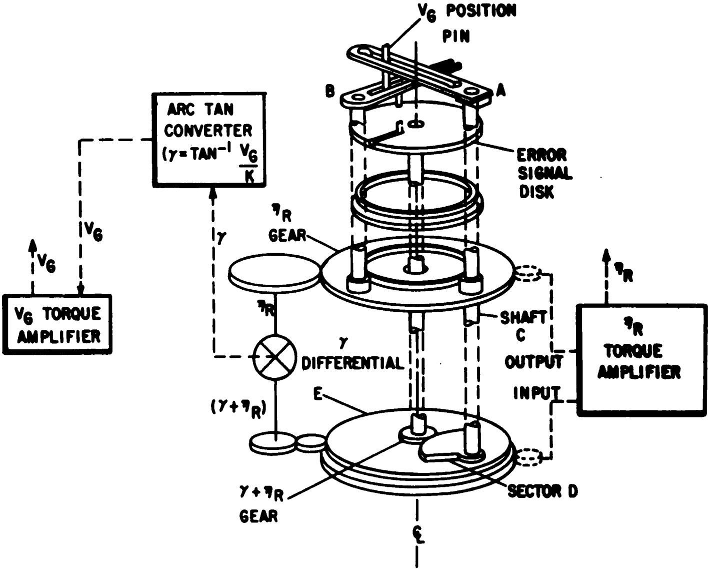


Figure 12–29.—Groundspeed converter and relative course solver.

slots of the two arms labeled A and B. The B arm; the η_R gear, which supports both arm A and arm B; and the bottom gear in the stack are concerned directly with the computation of η_R. The A arm and the $\eta_R + \gamma$ gear are concerned with the conversion of V_G from the vectorial form to an angular quantity.

The determination of relative course η_R will be discussed first. A pin rigidly attached to the underside of arm B rides in a slot in the error disk directly below it. However, the arm pivots on the η_R gear as shown in figure 12–29. The disk acts as a sensing device which detects any ANGULAR change of the V_G vector. Any detected error is transmitted by a common shaft to the bottom gear where it is picked off, amplified, and returned to drive the η_R gear.

The η_R gear will be driven in a direction to aline the slot in the error disk with the slot in the B arm, which is its null position. If the V_G vector changes in magnitude only, the V_G pin will move along the slots in the B arm and disk; thus, no error will be detected by the signal disk.

There will always be some value of η_R in the system; and as any change in the direction of the V_G vector is detected, the quantity η_R is immediately corrected. The output of η_R is taken from the torque amplifier by means of a gear train. (Torque amplifiers were discussed in chapter 6 of this course.)

Again referring to figure 12–29, it should be noted that the A arm is rigidly attached to shaft C; that shaft C passes through the arm support gear (η_R gear) and is rigidly attached to the sector gear D; and that the sector gear D imparts to the $\gamma + \eta_R$ gear any rotation of the C shaft and η_R gear (a change in η_R).

The C shaft and the B arm support shaft are 90 degrees from each other. Therefore, any change in the LENGTH of the V_G vector will cause only the A arm to rotate which is imparted to the $\eta_R + \gamma$ gear. The amount of this rotation is the angle whose tangent is equal to V_G and is represented by γ. Since γ and η_R are combined on one gear, it is necessary to employ a differential which subtracts η_R from it, leaving the quantity γ. This quantity is taken off the spider of the differential and transmitted to a converter which produces the desired linear V_G.

RELEASE POINT DATA COMPUTER

The purpose of the release point data computer is to solve the bombing problem based on data supplied to it by the tracking data computer and the various hand inputs. The solution of the bombing problem is essentially as follows:

1. Determination of the impact point, which is defined as the point where the bomb would strike if it were released from an aircraft.
2. Determination of the course change required for the path of impact points to pass through target.
3. Determination of the point along the course at which the bomb must be released based on solution of 1. and 2. above.

The release point data computer also supplies the pilot with the required course change and distance to go to the release point, allowing maximum use of evasive tactics. The major systems of the computer are the IMPACT POINT COMPUTING SYSTEM, A VECTOR SOLVER, and the BOMBING ORDERS SYSTEM. A block diagram of the release point data computer illustrating the relationship of the above systems is shown in figure 12–30. Each of the systems will be discussed in detail later.

Inputs and Outputs of the Computer

The release point data computer receives several inputs, some of which are from the tracking data computer. Others are manual inputs based on target data and bomb ballistic data.

The automatic inputs are:

1. Aircraft altitude above target	$H_O - H_T$
2. Vertical velocity	V_H
3. Airspeed	V_A
4. Groundspeed	V_G
5. Relative course	η_R

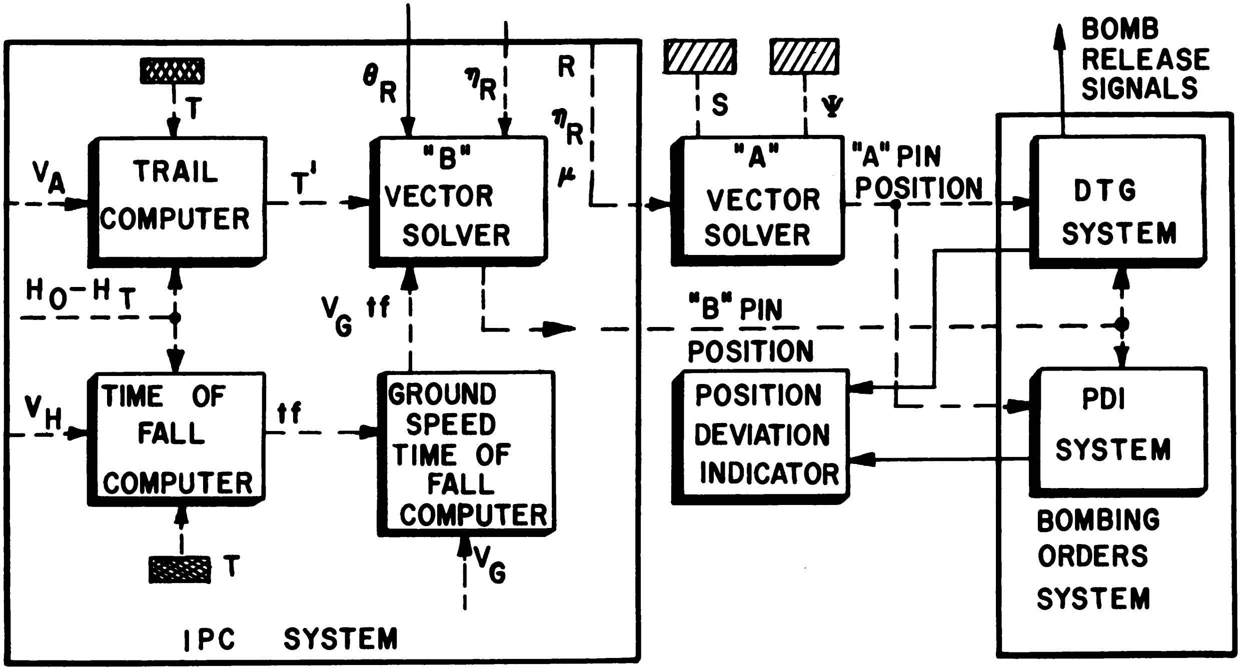


Figure 12–30.—Block diagram of the release point data computer.

6. Horizontal range	R
7. True bearing	μ
8. Relative bearing	θ_R

The manual inputs are:

1. Bomb ballistic setting	T
2. Aim point offset distance	S
3. Aim point offset angle	χ

The outputs of the release point data computer are:

1. Distance-to-go to release point.
2. Required course change.
3. Bomb release signals.

The inputs and outputs of the release point data computer are shown in figure 12–7.

Functional Analysis

The release point data computer is an analog computer which combines the various vector quantities in the solution of the three parts of the bombing problem. The first part is concerned with the computation of the impact point which establishes the *B* vector. The solution is based on inputs of V_G, V_A, $H_O - H_T$, θ_R, η_R, V_H, and T. The IMPACT POINT COMPUTING SYSTEM solves this portion of the problem.

The second part of the problem is concerned with the establishment of the present position of the target in respect to the aircraft. This is the *A* vector which is also established in the horizontal plane. The *A* VECTOR SOLVER establishes this vector from inputs of R, μ, π_R, S, and ψ.

The final solution of the bombing problem is accomplished by the BOMBING ORDERS SYSTEM which utilizes the A' vector for determining course correction and distance-to-go information. The A' vector, as discussed in the beginning of this chapter, is established by rotating the *A* vector until its head coincides with the projected path of the impact points. This part of the computer must determine the angle between the *A* and A' vectors and the difference in length between the A' vector and the *B* vector.

The three systems operate simultaneously giving continuous outputs. However, the operation of each system and its components will be discussed separately to facilitate understanding.

Impact point computing system.—This system shown in figure 12–30 determines continuously the B vector, and consists essentially of four major components—trail computer, time of all fall computer, V_G t_f multiplier, and the B vector solver.

The **trail computer** is primarily a mechanical device consisting of two mechanical multipliers. The trail computer develops trail T' output from inputs of ballistics T, altitude of the aircraft above the target, $H_O - H_T$, and true airspeed V_A. Trail, it will be recalled, is the distance along the ground between the point of impact and a point directly beneath the aircraft at the time of impact. It is computed by multiplying the three inputs together, using two multipliers. The trail T' output obtained in this manner does not have sufficient power to drive other mechanisms; therefore, a torque amplifier is used to boost the output power from the trail computer.

The multipliers employed in the trail computer operate on the same basic principles as discussed in *Aviation Fire Control Technician 3*, NavPers 10388.

Figure 12–31 illustrates the basic multipliers used in the computation of trail T'. The quantity $H_O - H_T$ from the

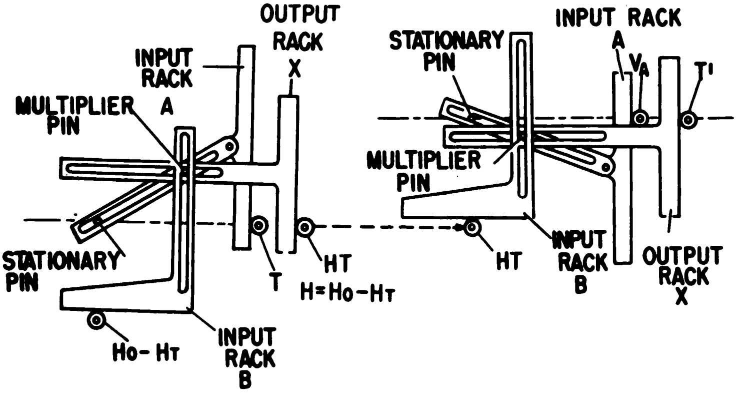


Figure 12–31.—Trail computer multipliers.

altitude and vertical velocity system positions the input rack B of the first multiplier which, in turn, positions the multiplier pin. T, which is set in manually, positions input rack A. This rack operates a pivot arm which forces the multiplier pin to a new position. The multiplier pin, in turn, causes the output rack to be positioned producing an output proportional to HT, which is $T\ (H_O - H_T)$.

The output of the first multiplier is transmitted to a second multiplier where it is multiplied by V_A in a similar manner. The output taken from its output rack is trail T'.

The TIME OF FALL COMPUTER computes the time required for a bomb to reach the target after it is released by the aircraft. This information is required by the groundspeed time of fall multiplier and is obtained by the device illustrated in the block diagram shown in figure 12–32.

The computer solves the basic equation

$$S = V_1 + 1/2gt^2$$

where S = Height of aircraft above target
V_1 = Vertical velocity of the aircraft
g = Acceleration due to gravity
t = Time of fall

This formula for time of fall does not take into consideration the air resistance acting on the bomb. However, air resistance is compensated for in the ballistic data for the particular type of bomb which is to be used. This is taken care of by the input T.

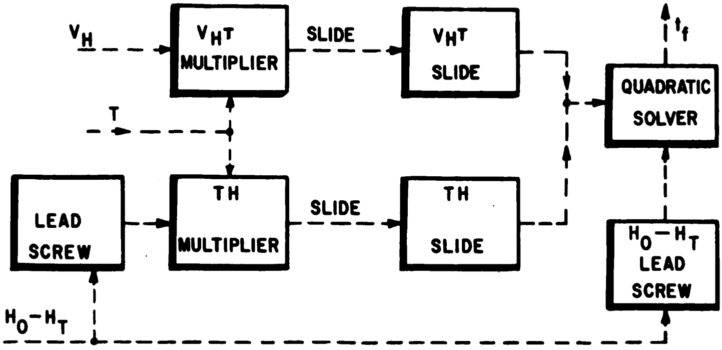


Figure 12–32.—Block diagram of the time of fall computer.

Referring to figure 12–32, the ballistic data T is applied to each of the multipliers. Rate of climb or dive information is applied to the V_HT multiplier. Similarly, altitude information in the form of $H_O - H_T$ is applied to the TH multiplier. (Multiplier operation is the same as discussed for the trail computer.) The outputs from the slides of each of the multipliers combine and position one leg of the quadratic solver as illustrated in figure 12–33.

The second leg of the quadratic solver is positioned by an input of altitude, $H_O - H_T$. It will be noted that the construction of the quadratic solver resembles a carpenter's square. The right angle arms are held in contact with the two input rollers by spring tension as illustrated in figure 12–33. Any vertical or horizontal movement of the $TH + V_HT$ roller or horizontal movement of the $H_O - H_T$ roller will cause the position of the right angle arms to vary and thus raise or lower the output arm which is restricted to vertical movement only.

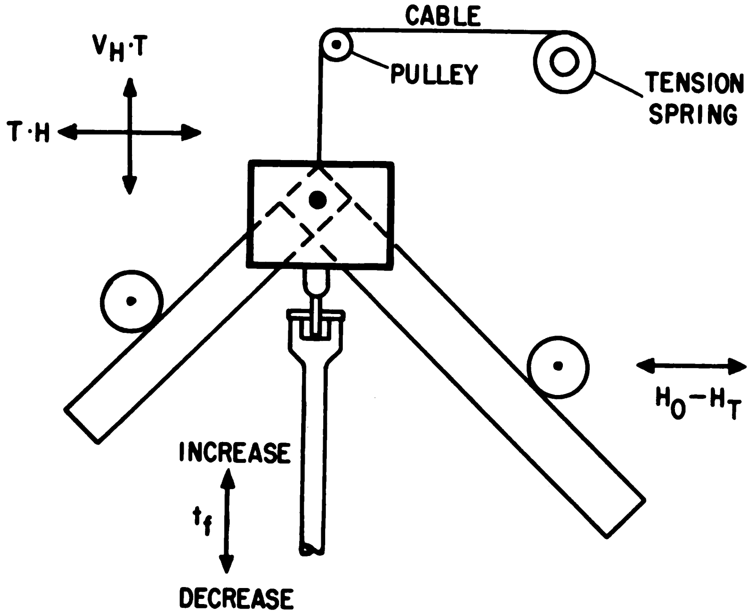


Figure 12–33.—Quadratic solver.

Downward movement of the output arm indicates a decrease in t_f, and an upward movement indicates an increase in t_f. The length of the output arm is proportional to t_f, and any apparent decrease or increase in length due to its being raised or lowered will be proportional to an increase or decrease in t_f.

The GROUNDSPEED TIME OF FALL MULTIPLIER does exactly as the name implies. The inputs of V_G and t_f are multiplied together and produce an output $V_G\ t_f$ which is proportional to the ground distance the aircraft will travel during the time of fall of the bomb. The output is taken from the output slide of the multiplier, amplified, and transmitted to the B vector solver. The $V_G\ t_f$ multiplier is essentially the same as those previously discussed and is illustrated by block diagram in figure 12–34.

The B VECTOR SOLVER receives the outputs of the $V_G\ t_f$ multiplier and the trail computer plus η_R and θ_R and continuously solves for the impact point of the bomb. The impact point of the bomb lies at the head of the B vector as illustrated in figure 12–35. The B pin is positioned at that point by $V_G\ t_f$, T', and k. The drift angle k is the difference between η_R and θ_R. Essentially, the B vector is the vector sum of the $V_G\ t_f$ and T' vectors.

As illustrated in figure 12–36, the quantity $V_G\ t_f$ causes a lead screw to position the turntable D along the fore-and-aft axis of the computer. The turntable center is positioned a distance from the zero reference position proportional to $V_G\ t_f$. The turntable is rotated by the output

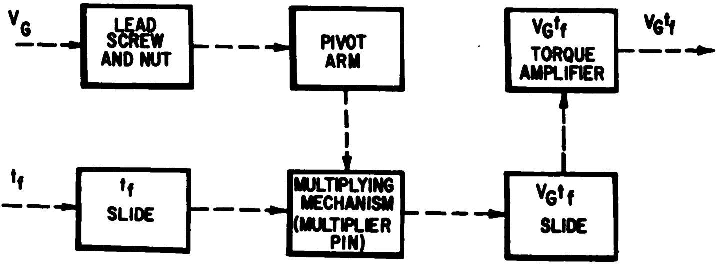


Figure 12–34.—Block diagram of the $V_G\ t_f$ multiplier.

of differential *F* which is proportional to the drift angle *k*. The quantity *T'* positions the *B* pin a distance from the center of the turntable *D* proportional to *T'*. The *B* pin now represents the head of the *B* vector which extends from point *O* to the *B* pin. A line drawn through the *B* pin and parallel to the $V_G\ t_f$ vector represents the path of impact points.

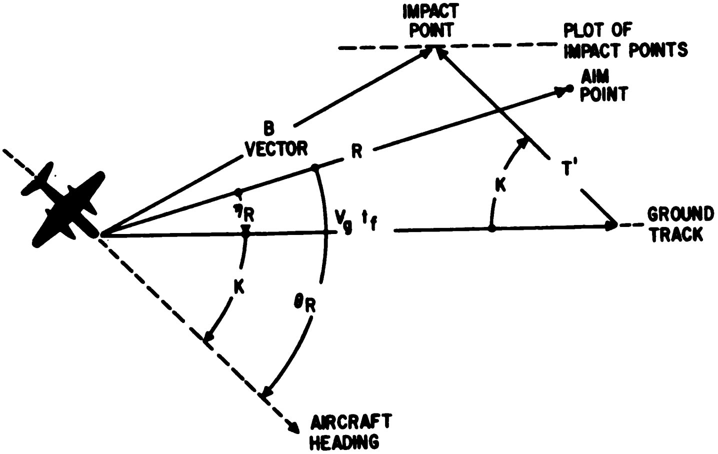


Figure 12–35.—*B* vector analysis.

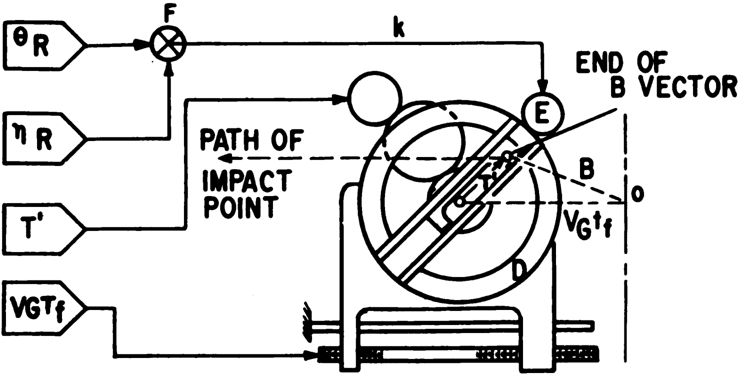


Figure 12–36.—The *B* vector solver.

THE *A* VECTOR SOLVER.—The *A* vector solver receives inputs of *R*, μ, ψ (offset angle), and *S* (offset distance) from which it establishes the *A* vector. The head of the *A* vector represents the present position of the target and is essentially the vector sum of *R* and *S* vectors as illustrated in figure 12–37.

Mechanization of the *A* vector solver will not be discussed in detail because the mechanics of establishing the *A* vector are essentially the same as for the *B* vector. A study of figure 12–37 will be sufficient to understand the function and operation of the *A* vector solver.

The *R* vector is established by causing the *A* pin to move a distance proportional to range and in a direction determined by μ. The *A* pin is then repositioned by the values of *S* and $(\psi - \mu)$; thus, vectorially adding the *S* vector to the *R* vector. The *A* pin now lies at the head of the *S* vector and represents the present position of the target. The *A* vector extends from the point representing the present position of the aircraft to the head of the *S* vector.

BOMBING ORDERS SYSTEM.—The *A* and *B* pins have been

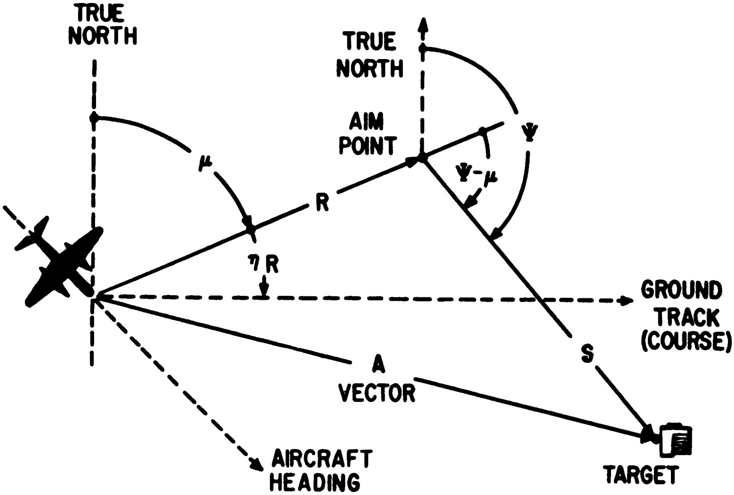


Figure 12–37.—A vector analysis.

positioned within the computer indicating the location of the target and the impact point, respectively. If the pins can be caused to approach each other by maneuvering the aircraft, and the bombs are released at the instant the pins become alined, a direct hit on the target should be obtained. It is the purpose of the bombing orders system to determine the information necessary to bring the impact points across the target and initiate the signals necessary to release the bombs.

In order for the pilot to maneuver the aircraft effectively in the final solution of the bombing problem, he must know how much to correct the aircraft heading (PDI angle) and the distance-to-go (DTG) to the target. This information is displayed to the pilot on the position deviation indicator.

The *A* and *B* vectors are mechanically constructed to scale on large individual turntables in the release point data computer. The turntables are located one beneath the other. The turntable on which the *A* vector is constructed is designed so that it may be rotated about the point of origin of the *A vector.* Thus, the *A* vector may be orientated in respect to the *B* vector.

A potentiometer will detect the angular error between the *A* and *B* vectors and develop an error voltage to energize a servo loop which will drive the *A* vector turntable. It will be driven until the *A* pin alines with the *B* pin along the path of the impact points as established in the computer. At its new position as indicated by the dashed line in figure 12–38, the *A* vector is now designated as the *A*' vector. Referring to figure 12–38 again, it will be noted that the PDI angle (τ) is measured between the *A* and *A*' vectors. Another potentiometer will detect the angle and develop a signal proportional to it. This signal will be transmitted to the position deviation indicator where the required heading change will be displayed to the pilot in terms of degrees.

As shown in figure 12–38 the DTG to the target is measured between the heads of the *B* and *A*' vectors. This

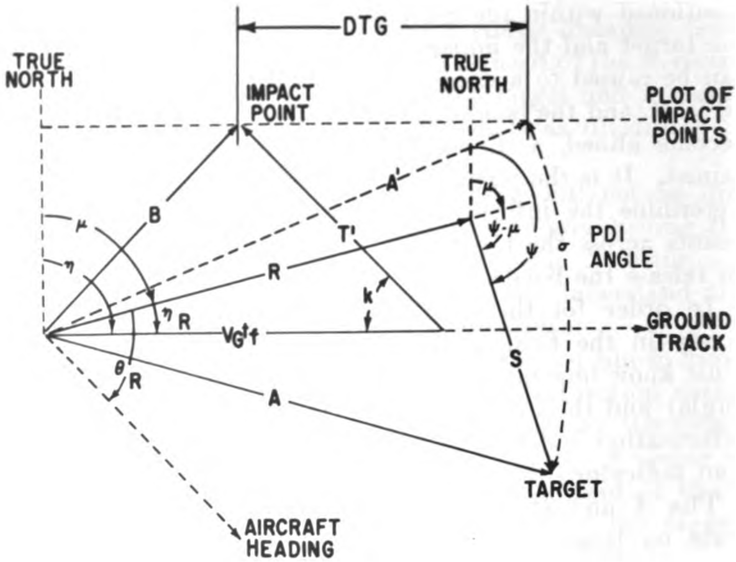


Figure 12–38.—Composite vector diagram.

information is also detected by a potentiometer which develops an error signal proportional to the DTG detected. The signal is transmitted to the position deviation indicator where the DTG is displayed to the pilot in miles.

As the aircraft heading is changed to bring the impact points across the target, the computer continues to solve the bombing problem. The process continues until the *A* and *B* vectors are parallel, and the only difference in them is length which is the remaining DTG to the target. This condition will be indicated to the pilot when the PDI needle is at zero. It is the pilot's responsibility to maneuver the aircraft so that the PDI needle will be zero prior to the DTG reaching zero.

When the DTG reaches zero, the *A* and *B* pins will aline exactly one beneath the other, and the bombs will be released. Various mechanisms and switching arrangements may be employed to open the bomb bay doors prior to the release time and also to close them after release.

MAINTENANCE

The mechanical computer discussed in this chapter is a precision device and must be maintained accordingly. For accurate and efficient operation, maintenance procedures should be strictly observed at all times. To insure the use of proper procedures, maintenance personnel should always refer to the *Handbook of Service Instructions* for the particular computer on which maintenance is being performed. Specific tolerances, adjustments, and procedures should never be trusted to memory.

This section will contain maintenance information pertaining to a typical bombing data computer and its subcomponents. Mechanical maintenance information was discussed in chapter 11 of *Aviation Fire Control Technician 3*, NavPers 10388, and should be reviewed. The maintenance information contained in this course will be on squadron level. However, many of the maintenance procedures on mechanical computers require specific test fixtures.

There are two main types of maintenance: preventive and corrective. Each will be discussed.

Corrective Maintenance

Maintenance procedures to correct the faulty operation of a fire control system or a part thereof may be considered corrective maintenance. This also extends to the subcomponents. There are two major steps to be considered in corrective maintenance procedures—trouble analysis, and removal and replacement of parts. Some phases of corrective maintenance may require that some preventive maintenance procedures be employed.

TROUBLE ANALYSIS.—Before making a trouble analysis of a computer, it is necessary to be reasonably sure that the trouble is in the computer and not some other unit of the fire control system. Isolating the trouble to the computer is not within the scope of this chapter and will not be discussed at this time.

The steps in correcting a malfunctioning computer are: analyze the trouble symptoms and determine possible causes and remedies for the abnormal operation. To effectively analyze trouble symptoms, it is essential that the technician have a thorough understanding of the theory of operation of the computer to be maintained. With this understanding, the task of trouble analysis will be simplified considerably.

The technician should bear in mind that a computer may have multiple troubles simultaneously, and therefore might indicate a variety of symptoms. This would complicate the technician's job considerably, requiring him to be very precise and discerning in his analysis of the malfunctioning computer and keeping unnecessary work to a minimum.

Most *Handbooks of Service Instructions* contain specific troubleshooting instructions to aid the technician and should be utilized regardless of his previous experience and training. Troubleshooting information is sometimes found in tabular form, such as troubleshooting charts, trouble analysis charts, or casualty analysis tables. These charts and tables are a composite tabulation of symptoms, causes, and remedies for troubles that occur frequently. However, they are not all inclusive, and troubles may occur for which these charts may be of little value.

In mechanical computers the trouble may normally be isolated to a subcomponent or a part thereof. When this has been done, the subcomponent must then be removed from the computer for repair or replacement. Squadron facilities are limited to the degree which corrective maintenance can be performed; therefore, no hard and fast rule can be established whether a subcomponent will be repaired or replaced.

When it has been determined that the defective subcomponent should be replaced, it should be forwarded to the designated maintenance activity for repair and adjustments. Components or subcomponents requiring shipment must be packaged in accordance with instructions found in the *Handbook of Service Instructions*.

REMOVAL AND REPLACEMENT OF SUBCOMPONENTS.—Before discussing this subject, it is essential that some consideration be given to the installation and removal of the computer from the aircraft.

Some mechanical computers are quite large and heavy, requiring special handling equipment and several men to handle them effectively. Their location in the aircraft may also complicate their removal and/or replacement. Personnel concerned with the removal and/or installation of mechanical computers should familiarize themselves with the particular aircraft installation with which they are working. The SAFETY of personnel and equipment should be of prime concern at all times. DAMAGE to the computer and the aircraft can occur easily if care is not exercised in the installation and removal of a computer of this type. Personnel may also be injured if special precautions are not taken for their safety.

The aircraft's *Handbook of Maintenance Instructions* should be consulted for specific procedures to be followed in the installation and removal of the computer. A checklist will normally be provided which should be followed to prevent damage to the computer or other aircraft accessories. In either removal or installation of the computer, the technician must make the necessary preparations to both the aircraft and the computer. Particular attention should be given to connections and fasteners before removal and after installation.

Prior to the installation and/or removal of subcomponents, it is essential that certain procedures be followed. The technician should remove all dirt and dust from the outside of the computer case. This should be done outside the computer shop, since dust and dirt entering a mechanical computer can have a very adverse effect on its operation, causing a considerable amount of unnecessary cleaning. Prior to removal and/or installation of subcomponents, the computer inputs should be set in accordance with instructions contained in the *Handbook of Service Instructions*. In removing or installing subcomponents, extreme care should be exercised not to exert force on the unit since considerable damage to shafts, gears, couplings, and electrical connections may result.

Following the removal of a subcomponent, it should be placed under a lint-free cloth or cover when not undergoing repairs. The computer should also be kept covered in a similar manner or the covers and plates should be replaced, keeping the computer sealed against dust and dirt.

Installation of subcomponents in a computer requires a considerably more delicate procedures than their removal. The *Handbook of Service Instructions* should be consulted and every detail of subcomponent installation taken into consideration. A list of details to be checked might be as follows:

1. Order of subcomponent installation.
2. Recheck of computer knob and dial settings.
3. Proper zeroing of subcomponents.
4. Alinement of couplings, gears, and shafts.
5. Proper seating of the subcomponents. (Do NOT FORCE.)
6. Mounting screws properly tightened.
7. Security of all internal connections.
8. Removal of all zero setting pins from subcomponents.
9. Computer covers and plates properly sealed.

When subcomponents are installed in a computer, certain adjustments and performance checks must be made on the computer. These items will be discussed in a subsequent section of this chapter.

Preventive Maintenance

The most effective maintenance is preventive maintenance. Experience has proven that the better care given an equipment, the longer it will give trouble-free operation. Preventive maintenance consists of doing those things that will prevent a device from malfunctioning for a longer period of time and also increasing its useful life. For mechanical computers and their subcomponents, this type of maintenance consists primarily of cleaning, adjusting, and lubricating components at periodic intervals.

The *Handbook of Service Instructions* should be consulted for specific procedures to be followed, cleaning fluid specifications, clearances, and adjustments. It should be remembered that some preventive maintenance procedures may also be performed while performing corrective maintenance.

CLEANING.—As indicated in the section on corrective maintenance, dust and dirt can present a serious problem in the maintenance of mechanical computers. The working area where maintenance work and especially preventive maintenance is performed should be as free of dust, dirt, and moisture as circumstances permit. Smoking should not be permitted in the working area because of the ashes; fire hazards are also involved when cleaning fluids are being used. Food and beverages carried into the working spaces of this nature may also present a serious problem.

The cleaning of mechanical parts may seem like a trivial matter to the technician. This, of course, is not true. The technician will be required to be precise and discerning in the preparation of the computer for cleaning as well as during the actual cleaning. Many subcomponents are not to be disassembled for any reason. Thus, care must be exercised in cleaning to prevent the cleaning solvent from getting into places that cannot be lubricated properly without disassembly. The *Handbook of Service Instructions* should always be consulted for procedures peculiar to the computer or subcomponents to be cleaned.

Mechanical parts and housings should generally be wiped or brushed with the prescribed solvent to remove excess lubricant and foreign matter. A similar procedure will also be followed in cleaning electrical components. Care should be exercised not to use items in cleaning that will scratch or mar smooth contact surfaces, whether electrical or mechanical. After the solvent has been applied, all accessible surfaces should be wiped dry with a clean lintless cloth.

INSPECTION.—After cleaning and prior to lubrication, the computer and its subcomponents should be inspected thoroughly for defects, especially those resulting from wear, tion gear. It should be remembered that the V_A vector is positioned in relation to the head of the V_W vector and that groundspeed is measured from the projected center line of the wind vector solver to the V_G pin. The relationship of these vectors is extremely important and should be thoroughly understood before going further in the computer.

As the V_G pin is positioned it is simultaneously positioning two racks, the outputs of which are the rectangular components of V_G. They are V_μ and V_R.

GROUNDSPEED CONVERTER AND RELATIVE COURSE SOLVER.—Relative course, η_R is the clockwise angle that lies between the range line and ground track as illustrated in figure 12–3. The relative course solver, shown in figure 12–29, not only solves for η_R but also produces an angular quantity γ representing nonlinear V_G.

Referring to figure 12–29, note that the V_G position pin, which extends from the airspeed vector solver, rides in the

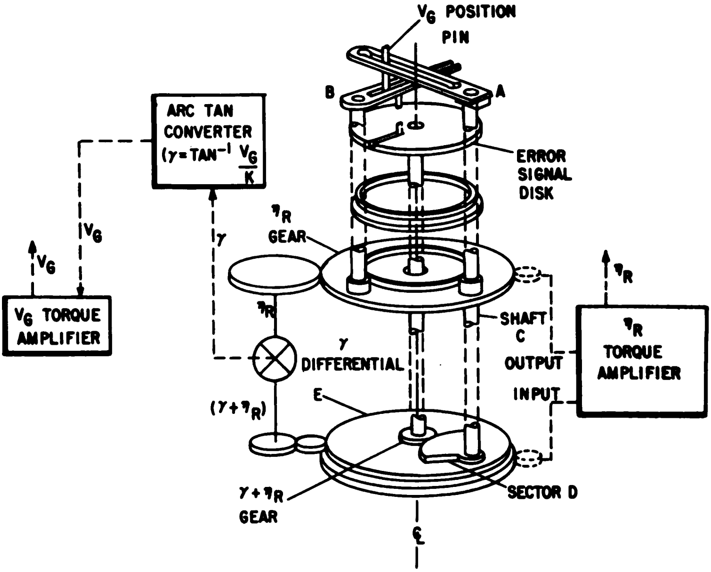


Figure 12–29.—Groundspeed converter and relative course solver.

slots of the two [illegible]
η_R gear, which [illegible]
bottom gear in [illegible]
computation of [illegible]
concerned with [illegible]
form to an angular [illegible]

The determination [illegible]
first. A pin [illegible]
rides in a slot [illegible]
ever, the arm [illegible]
12–29. The [illegible]
ANGULAR change [illegible]
transmitted [illegible]
it is picked off [illegible]

The η_R gear [illegible]
slot in the [illegible]
its null position [illegible]
only, the [illegible]
and disk: [illegible]

There [illegible]
and as any change [illegible]
detected. [illegible]
output of η_R [illegible]
of a gear [illegible]
chapter 6 of [illegible]

Again ref[illegible]
the *A* arm [illegible]
passes through [illegible]
idly attached [illegible]
D imparts [illegible]
and η_R gear [illegible]

The *C* [illegible]
grees from [illegible]
LENGTH of [illegible]
rotate which [illegible]
this rotation [illegible]
represented by [illegible]
gear, it is necessary [illegible]

deterioration, or improper handling. The subcomponents should be inspected without disassembly unless prescribed in the *Handbook of Service Instructions.* Lighting is especially critical in examining subcomponents for defects. Inspection lights, hand mirrors, dental mirrors, and magnifying glasses can be used to a great advantage to inspect partially hidden parts and small details. The technician should be especially watchful for such defects as:

1. Broken, chipped, burred, bent, and badly worn parts.
2. Dirt particles embedded in gear teeth and bearings etc.
3. Cracked or broken housings or castings.
4. Loose connections, retaining rings, sleeve pins, and spring-loaded couplings.
5. Rust and corrosion.
6. Defective electrical connections.

When defects are located, the technician should consult the *Handbook of Service Instructions* and his immediate supervisor to determine whether the subcomponent or part should be repaired or replaced.

LUBRICATION.—Following the inspection of the computer and its subcomponents, the next step in preventive maintenance is the lubrication procedure. The tendency of many people is to apply excessive lubricant to mechanical parts. Excessive lubrication can cause as much damage as a lack of lubrication. Foreign matter will collect easily on parts that have been excessively lubricated. Electrical contacts may also become gummed and fail to function properly.

Lubricants should be applied uniformly to computer and subcomponent lubrication points as indicated by the *Handbook of Service Instructions.* Only the lubricants specified should be used. An assortment of brushes, oil guns, hypodermic syringes and needles, clean pieces of copper wire, and lintless cloth patches are essential for a thorough and effective job of lubrication. The working area and equipment to be used should be kept as clean and free of foreign matter as circumstances permit. Care should be exercised to prevent moisture and perspiration from getting on precision parts. Applying a film of oil to the hands before handling precision or machined parts will help eliminate this condition.

Alinement and Adjustment

When any corrective or preventive maintenance has been performed on a computer, it is essential that it be thoroughly alined in accordance with specifications found in the *Handbook of Service Instructions.* Unless checks and adjustments are made to aline the computer properly, its computations may be in error, and thus ineffective delivery of the aircraft stores may result.

Most fire control systems and computers require the employment of special test sets. The test set for the computer to be checked and alined will have a *Handbook of Operating Instructions* containing all necessary information pertinent to its operation. The test set will usually be a portable unit and contain provisions for connecting it to the computer. Additional instruments to perform a complete performance check, such as stopwatches, tachometers, and strobotacs will also be required.

Caution: Before applying power to the equipment and test set, insure that all setting pins have been removed and stowed in their proper spaces.

The *Handbook of Service Instructions* for the computer should be consulted for the procedures to be used in making all checks and adjustments required to aline the computer. It will be necessary to check the computer to insure that there are no erroneous values present. The remainder of the computer check is essentially a check of each system in the computer until all have been checked and adjusted as required.

First, the time drive motor or mechanism must be adjusted to the prescribed r.p.m. Second, it will be necessary to insure that all wind values are at zero. Dial readings of zero are not positive indications of this. Therefore, it is necessary to perform a prescribed check and make the necessary adjustments to remove any value of wind that may appear.

The rate adjustments must be checked next prior to initiating the individual computer system checks. This is done by setting in a specific test problem and checking the range and true bearing dial readings against values calculated for the test problem at specific intervals of time. If the indicated values are not correct, the rate integrators should be adjusted as prescribed. Normally, this will be a screwdriver adjustment to the integrator ball carriages.

When the preliminary checks have been completed, the computer is ready for performance checks on its various systems. Each check may test a complete system or portions of several systems; therefore, the name of any one check does not necessarily indicate the system to be analyzed. The checks pertinent to the type computer discussed in this chapter will be listed without a detailed discussion. The only procedures that should ever be used are those found in the *Handbook of Service Instructions* applicable to the computer being tested.

The TRUE AIRSPEED TEST checks the performance of the true airspeed computing system and its various component parts. It may be necessary to know the local static atmospheric pressure and to use a conversion table to determine what the value of correct true airspeed should be.

The RADAR VOLTAGE TEST checks the performance of the slant range and elevation angle computing system. In this test the output signal voltages are checked against voltages calculated for the specified values of altitude (aircraft and target) and range inserted in the computer.

The HEADING TEST checks the heading system. With zero wind value inserted, the course indicator of the computer should agree with the test set indicator at all times.

The WIND TEST checks the wind resolver of the range and true bearing rate system and the groundspeed converter. The test indicates the accuracy of the computer in resolving wind components with changes in true bearing.

The BOMB RELEASE TEST checks the entire release point data computer. In this test all necessary data is supplied by dial settings based on a test problem. The computer should then accurately solve for the bomb release point. Its results are compared against the mathematical solution of the problem using the same input data.

The WINDS CORRECTION TEST checks the performance of the correction unit which is employed in the azimuth, range, and range and true bearing rate systems.

The LIMITS TEST is essentially a check of the various components of the computer for trouble-free operation. The components are operated between their maximum and minimum operational limits.

The technician should bear in mind that if the results of any test are not within the tolerances specified in the *Handbook of Service Instructions* for the specific computer, the necessary corrections must be made to the computer. No attempt has been made in this course to indicate specific adjustments, but primarily to familiarize the technician with performance checks for computers of this type.

QUIZ

1. The A vector is obtained by vectorial addition of
   a. R vector and S vector
   b. R vector and B vector
   c. V_Gt_f vector and trail vector
   d. S vector and trail vector

2. The B pin represents the
   a. point of impact
   b. aim point
   c. present position of the aircraft
   d. target

3. The large lead screw in figure 12–36 is rotated by
   a. V_Gt_f
   b. trail $+ \eta_R - \phi_R$
   c. horizontal range
   d. trail

4. The target offset (S) input establishes the
   a. magnitude of the S vector
   b. direction of the S vector
   c. magnitude of the R vector
   d. magnitude and direction of the S vector

5. Mechanized bridge circuits are found in which of the following systems?
   a. Trail computer and azimuth integrator
   b. Slant range and elevation angle system and true airspeed system
   c. Heading servo and synchro unit and AVVM
   d. Correction unit and $V_G t_f$ multiplier

6. In the component solver of the V_G computer, the angle of the input vector is established by means of a gear with a radial slide. The magnitude of the input vector is set up by means of a
   a. relative heading cam
   b. vector solver
   c. V_G pin
   d. constant lead cam

7. In which of the following is a torque boost mechanism associated with an integrator?
   a. Range reciprocal integrator
   b. Range integrator
   c. Azimuth integrator
   d. Azimuth displacement integrator

8. In the groundspeed computer, nonlinear groundspeed is changed to a linear value by
   a. use of a 4-to-1 step-up gear system to cause the nonlinearity to be dissipated
   b. combining η_R and γ in a differential
   c. feeding the nonlinear value to a tangent solver
   d. limiting groundspeed to its most linear values

9. In the time of fall computer
   a. an increase of aircraft altitude above the target will cause the output arm to extend farther from the unit
   b. computations are accomplished by purely mechanical means
   c. the V_H input compensates for the effect of airspeed on time of fall
   d. a torque amplifier is used to provide a more powerful output

10. The constant speed motor in the computer provides
   a. rotational power at various speeds
   b. rotational power only
   c. a time reference only
   d. rotational power and a time reference

11. When the ball carriage of the ${}_{R}V_{W}$ integrator in the wind resolver subunit of the computer is at its zero position, the ball carriage of the μV_{W} integrator will
    a. represent the value of V_{W}
    b. be at its zero position
    c. be at its maximum positive value
    d. be at its maximum negative value

12. Torque amplifiers are used to increase the power of a/an
    a. linear motion
    b. eccentric motion
    c. rotational motion
    d. intermittent motion

13. Output rotation of the range reciprocal integrator
    a. changes in speed only
    b. changes in speed and direction
    c. is constant
    d. has two fixed rates only

14. The integrator disk of the azimuth integrator is rotated at
    a. three different speeds
    b. two different speeds
    c. one speed only
    d. various speeds depending on range

15. The value which is a manual input to the heading servo and synchro unit is
    a. magnetic heading
    b. magnetic variation
    c. true heading
    d. true bearing

16. When the wind resolver is operating properly, an input of $\Delta_{R}V_{W}$ will
    a. rotate the disks of both integrators
    b. turn the roller of the range wind change integrator
    c. move the carriage of the azimuth wind change integrator
    d. turn the manual ${}_{R}V_{W}$ input knob

17. ${}_{R}V_{W}$ and μV_{W} are added together vectorially to produce the V_{W} vector in the
    a. groundspeed computer
    b. wind resolver
    c. range and azimuth correction unit
    d. slant range and elevation angle computer

18. In the true airspeed computer V_A equals 350 knots. As P_s increases (all other inputs remaining unchanged), the output value of V_A should
    a. decrease
    b. increase
    c. remain the same
    d. change, but from data given it is impossible to determine the direction of change

19. When making a rate correction (wind run), an increase in $_RV_W$ and $_\mu V_W$ will
    a. increase the V_A component in the V_G computer
    b. not affect the V_G vector
    c. have no effect on the ball carriages in the wind resolver
    d. affect the V_R and V_μ outputs of the V_G computer

20. If computed H_0 is too large,
    a. the output of the trail computer will be accurate
    b. this would have no effect on the accuracy of the computer
    c. the output of the V_Gt_f multiplier will be in error
    d. H_T will also be too large

21. Which of the following quantities is NOT used in the trail computer to solve for trail in feet?
    a. Aircraft altitude above target
    b. Aircraft vertical velocity
    c. Ballistics
    d. True airspeed

22. The H input to the slant range and elevation angle computer originated in the
    a. gyroscope
    b. range limits mechanism
    c. heading servo and synchro unit
    d. altitude and vertical velocity meter

23. The total number of inputs to the time of fall computer is
    a. one
    b. two
    c. three
    d. four

24. The V_G input information to the V_Gt_f multiplier is obtained from the
    a. range integrator and gear shift
    b. groundspeed computer and integrator
    c. azimuth integrator
    d. wind resolver

CHAPTER 13

MATERIAL AND SPARE PARTS

Due to the complexity of aviation fire control equipments, it is necessary that a large volume of spare parts and maintenance material be stocked and be available for issue. The method of obtaining this material is of prime importance to all Aviation Fire Control Technicians. The purpose of this chapter is to acquaint you with these methods, and provide a working knowledge of the aviation supply system.

AVIATION SUPPLY SYSTEM

The aviation supply system is built around a central organization known as the Aviation Supply Office (ASO). The Aviation Supply Office is located at Philadelphia, Pa., and operates under the joint authority of the Bureau of Supplies and Accounts and the Bureau of Aeronautics. The Bureau of Supplies and Accounts controls the personnel, administrative procedures, and operating funds of the Aviation Supply Office. The Bureau of Aeronautics controls the categories of material purchased and distributed by the Aviation Supply Office, and supplies the funds for such purchases.

The primary functions of the Aviation Supply Office are the determination of aviation material requirements and the procurement, storage, distribution and redistribution of these materials in a manner to allow maximum operating efficiency of naval aviation units.

In determining aviation material requirements, the Aviation Supply Office must base its estimates primarily on the naval aircraft program and the operational plans of the Navy Department. It also utilizes a reporting procedure for the collection of usage data which is analyzed and used in estimating future requirements for aeronautical materials.

Additional functions of the Aviation Supply Office are as follows:

1. Classification and cataloging of aeronautical material.
2. Distribution of ASO Navy Stock List.
3. Inventory control of aeronautical material.
4. General control of critical aeronautical material with exception of that material controlled directly by BuAer and fleet commands.
5. Disposal of surplus aeronautical material.

Material Control

The distribution of all aviation material is under the control of some office or bureau of the Navy Department or Fleet Command. That material under the latter control is known as FLEET-CONTROLLED MATERIAL, and includes those items that are critical due to shortages of supply. Designation of items as fleet-controlled material is made by ASO in the ASO Monthly Inventory Report of Special Items on the basis of recommendations made by the Fleet Commands. Distribution and issuance of fleet-controlled material is made only upon the approval of representatives of the fleet.

The theory behind this system of rationing is that such scarce materials must be used where needed most, and the respective Fleet Commands, being well acquainted with their own operational requirements, are the people most aware of which activity will have the greatest need for each item of critical material.

Distribution of items of aeronautical material is under the control of either the Bureau of Aeronautics, Bureau of Ordnance, or others. The nature of the material determines the cognizant agency. The controlling agency limits the distribution of highly technical matters involved in its use, design, specifications, etc. Material subject to BuAer control is the largest category in this grouping, and is often referred to as Bureau-Controlled Material.

Inventory Control for the majority of material under the cognizance of BuAer is delegated to ASO.

The following is a partial list of the control symbols and the cognizant control office or bureau that should be of interest to the Aviation Fire Control Technician.

Cognizance control symbol	*Cognizance supply control office or bureau*
J	Bureau of Ordnance
N	Electronics Supply Office
Z	Ordnance Supply Office
R	Aviation Supply Office
V	Bureau of Aeronautics
I	Forms and Publications Supply Office

Distribution

To facilitate distribution of aeronautical material, the Aviation Supply Office has established several supply activities. These are:

1. Reserve stock points.
2. Distribution stock points.
3. Primary stock points.
4. Secondary stock points.
5. Satellites.

The function of each of the supply activities is described as follows:

RESERVE STOCK POINTS.—Reserve stock points are activities which carry reserve and backup stock for the supply system. These units maintain storehouse facilities for the bulk storage of aeronautical material.

DISTRIBUTION STOCK POINTS.—Distribution stock points are activities carrying stock for the supply support of designated PRIMARY and SECONDARY stock points within the continental U. S., fleet units, yards, and district craft.

PRIMARY STOCK POINTS.—Primary stock points are units carrying stock for their own consumption and for the supply support of designated activities as SECONDARY STOCK POINTS, fleet units, yards, district craft, and assigned aircraft. Primary stock points also furnish complete aeronautical supply support to activities designated as SATELLITES.

SECONDARY STOCK POINTS.—Secondary stock points are nonreporting units which carry stock for their own consumption and for the support of assigned aircraft. These activities are all shore-based units, continental or extracontinental, which are not classified at a higher level.

SATELLITES.—Satellites are aeronautical activities which

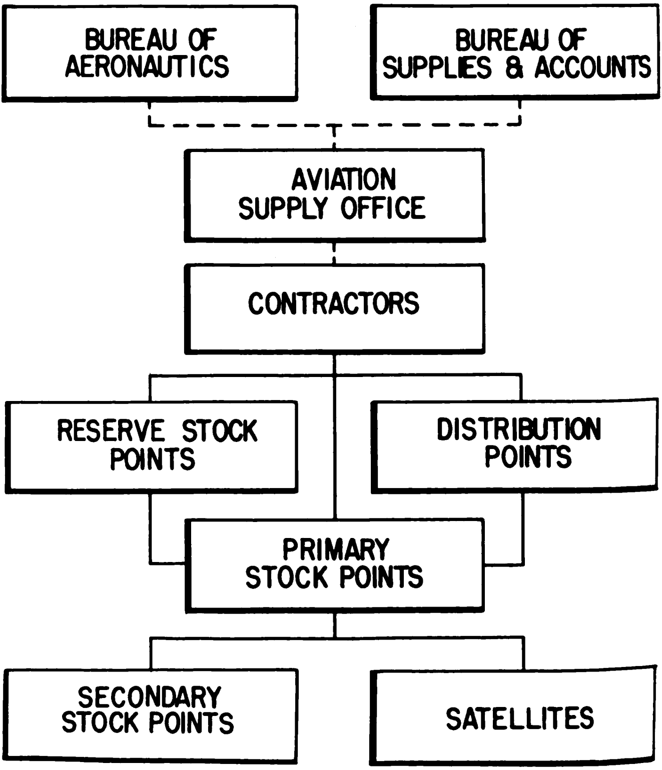


Figure 13–1.—Flow chart of aeronautical material.

are dependent on a primary stock point for complete aeronautical supply support. Such activities will usually be an auxiliary air station, air facilities, or other minor supply activities.

The relationship existing between the various units of the aviation supply system can best be understood by studying the flow chart of aeronautical material shown in figure 13–1.

Accounting

Every naval expenditure is chargeable immediately or ultimately to an appropriation. These appropriations pay the general operating and maintenance expenses of the Navy. The Navy allows each of its major departments an allowance of money with which to carry out its assigned duties. Each department, in turn, allocates a fixed sum to each of its subordinate activities and units for payment of their individual operating and maintenance expenses. The supply officer or comptroller at each activity is required to keep an accurate account record of all allotments granted to each department. He must also keep the head of each department informed as to the current status of his allotment in regard to amounts expended and the balance remaining.

Charges and credits to appropriations are reported to the Bureau of Supplies and Accounts in order that the status of each appropriation may be determined at any time, and in order that transactions under each appropriation may be communicated to Congress as required by law. It should now be obvious why each person ordering material must exercise extreme care in supplying accurate cost and other appropriation data.

PROCUREMENT BY MAINTENANCE ACTIVITIES

Maintenance activities must procure parts and material to be used by their activity and any activities for which they provide support. This includes procurement of material for stock, immediate use, and replacement of defective items. The procedure for ordering material was discussed in chapter 14, *Aviation Fire Control Technician 3*, NavPers 10388. However, the justification for ordering material, along with the use of Navy stock lists, will be discussed in this section.

Allowance Lists

Allowance Lists and Tables of Basic Allowances consist of listings of the equipment and material (both expendable and accountable) necessary to place and maintain activities of the aeronautical organization in a material readiness condition. Allowances contained therein are based on known or estimated requirements and on available usage data. Bureau of Aeronautics Allowance Lists and Tables of Basic Allowance should not be confused with catalogs or lists of available material.

BuAer allowance lists are known by "sections." Certain sections are issued as individual publications while other sections will be composed of a series of individual publications, with each publication being applicable to a specific model of equipment, aircraft, or activity.

When ordering Allowance Lists and Tables of Basic Allowances, be sure to specify the lists desired by "section" (alphabetical designation), title, effective issue date, and NavAer number. All applicable changes to basic lists will be included with the original lists. In the event the issue requested has been superseded, the latest effective reissue with all applicable changes will be furnished. Allowance Lists and Tables of Basic Allowances are reissued periodically. When new issues or reissues are published, they will be listed in the next reissue or supplement of the *Naval Aeronautic Publications Index* (NavAer 00–500).

The sections of the allowance lists with which the AQ2 will be most concerned are as follows:

Section A—Standard Aeronautical and Navy Stock Account Material.
Section G—Shop-handling and Servicing Equipment.
Section K—Naval Aeronautic Publications and Forms.
Section R—Aeronautical Electronics Material.

Section O—Aviation Armament Equipment including aviation fire control equipment.
Section U—Standard Hand Tools for Aircraft Maintenance Activities.

Federal Supply Classification System

For many years, there were nearly as many ways of listing and classifying supplies as there were federal bureaus and services. The Army, Navy, and Air Force each had their own system of classifying, identifying, and cataloging supplies. In many instances, a given item would be listed in several different supply systems under different identifying numbers. Because of this situation, certain items of supply were often critically scarce in one system, while there might be a surplus of these items in another system. In such a case, the artificial shortage would cause the expense of buying new supplies for one system when they were already available in another. The personnel operating one supply system had no way of knowing what another system might have on hand. Obviously, inefficiency and unnecessary expense resulted from these methods of handling federal supplies.

To prevent this waste, Congress passed Public Law 436 establishing authority for the Defense Department to devolop a single federal cataloging system and a related program of supply standardization. The basic purpose of this program is to identify each item with a distinctive name and number. In this way the name and stock number of a given item of supply will be the same in all the services, bureaus, and departments of the government.

All items of federal stock are identified and cataloged by the Munitions Board for the Federal Government. This information is furnished all military cataloging activities via the Department of Defense on Electric Accounting Machine cards (EAM cards).

The Bureau of Aeronautics has delegated the Aviation Supply Office the responsibility of cataloging all items common and peculiar to the aviation supply system. The Cataloging Division of the Aviation Supply Office prepares and maintains a master file of EAM cards for all items in the naval aviation supply system. From this master file of EAM cards, the *Navy Stock List of the Aviation Supply Office* is prepared and will be discussed in the next paragraph. Other stock lists the Aviation Fire Control Technician will find necessary to use are:

1. Navy Stock List of General Stores.
2. Navy Stock List of the Electronic Supply Office.
3. Navy Stock List of the Ordnance Supply Office.

NAVY STOCK LIST OF THE AVIATION SUPPLY OFFICE.—This publication contains a list of all material under the cognizance of ASO and is comprised of five sections. They are as follows:

1. CROSS-REFERENCE. From manufacturer's part number and code to federal stock number.

2. CROSS-REFERENCE. From federal stock number to manufacturer's part number and code.

3. STOCK NUMBER DATA SECTION. This section is used to indicate the availability of the item plus the unit of issue, unit price, accountability code, new items, and deleted items. It is published in weekly segments to effect complete revision quarterly, thus the stock list can be kept up-to-date continuously.

4. DESCRIPTIVE SECTION. This section serves as a cross-reference between the characteristics and the stock numbers of common usage items. It is used to locate stock numbers when only names and/or physical characteristics are known, and to determine possible replacements or substitutes for critical items. Revisions are published as required and are based on the percentage of change.

5. PARTS LIST SECTION. This section is used to supplement information contained in the *Illustrated Parts Catalogs.* Additional information in this includes cross-references from part numbers to stock numbers, supersedure of numbers, additional model applications, equivalents, change of design information, maintenance and overhaul percentages,

accountability, perishability, salvageability, and indications as to whether items are included in allowance lists.

FEDERAL STOCK NUMBER.—A stock number in the Federal Supply Classification (FSC) System is called a Federal Stock Number (FSN). A knowledge of the composition and breakdown of the FSN into its various parts is very beneficial to the AQ2 in identifying and locating material.

The FSN is composed of 11 digits arranged in groups of 4, 3, and 4, separated by hyphens. For example, 1630-123-4567 is a sample FSN. The first 4 digits are referred to as the federal stock CLASS CODE NUMBER. Of these digits the first 2 indicate the federal stock GROUP. The last 7 digits of the FSN are called the Federal Item Identification Number (FIIN).

The FSC numbering system consists of 99 groups which are further subdivided into classes. Each group covers a relatively homogeneous area of commodities and each class subdivides the group into specific commodities. An example of group and class breakdown is:

Group 53	*Hardware*
Class 5305	Screws
Class 5306	Bolts
Class 5307	Studs

The 7 digit FIIN is serially assigned each item as it is identified on the EAM cards. Thus, a similar succeeding item will not have the same number assigned. The FIIN is essentially the stem of the FSN and has no particular significance other than identification. An example of FIIN assignments may be:

186–9431	Sight head, illuminated
186–9432	Sight head, illuminated, reflector type
213–9965	Sight unit, computing

CODED FEDERAL STOCK NUMBERS.—This is the number with which the individual will normally be concerned, and is composed of the FSN with addition of four Supply Management Codes. Coded stock numbers are not new under the FSC system except for the addition of one more Supply Management Code giving a total of four. The prefix codes are the Cognizance Symbol, Fraction Codes, and Material Condition Codes. The new code is the Technical Supply Management Code which is a four-character suffix attached to the FSN, and is peculiar to the Navy Stock List of the Aviation Supply Office.

The COGNIZANCE SYMBOL was discussed in the section on Material Control of this chapter, and will not be discussed further at this time. The FRACTION CODE indicates whether an item is a slow or fast moving item in the supply system, or locally stocked, locally controlled, or that the item is designated for special projects. It is primarily for the use of people in the supply department, and bears little significance for maintenance personnel. The MATERIAL CONDITION CODE is also a code that is primarily used by the personnel of the supply department. It is not necessary for the technician to know the code, only that it is included as part of the stock number.

The TECHNICAL SUPPLY MANAGEMENT CODE (TSMC) will suffix each stock number in the Navy Stock List of the Aviation Supply Office. The suffix will consist of a combination of a letter and three numerical digits (for commodity type material or grouping of small manufacturers) or a group of four letters (to identify major manufacturers).

The TSMC is assigned primarily for use in inventory control and reporting. However, the Aviation Fire Control Technician may find it useful in identifying types of material and determining the manufacturer.

The TSMC may be broken into two parts. The first letter will indicate a material group or line of material within that group. There are several material groups to be indicated, of which two examples of interest to the AQ are:

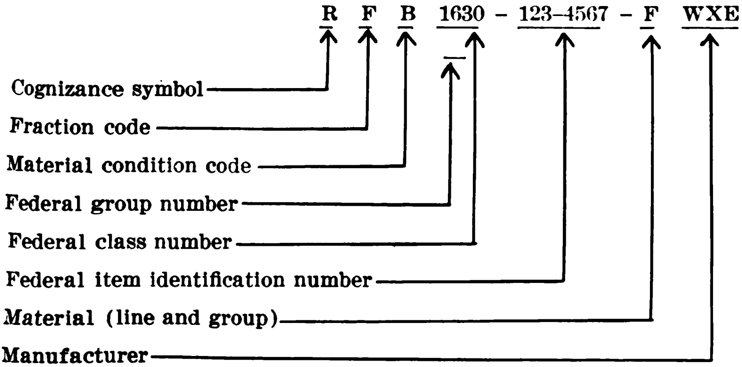
Material Group	*Code*	*Line of Material*
Electronics	D	Electrical
	E	Class 16—SNSN
	F	Radio, Radar—Test equipment
	M	Missiles
Shop equipment	R	Auxiliary power units
	S	Shop equipment and tools
	T	Special instrument tools

The AQ will be concerned primarily with the second part of the TSMC that is composed of letters rather than digits, thus indicating manufacturers. Some examples of this portion of the TSMC are:

Code	*Manufacturer*
WXE	Westinghouse
CVA	Chance Vought
BEA	Beech
JHA	Jack and Heintz

Typical Coded Federal Stock Number.—Thus far in the discussion of the Federal Supply Classification System, the identification of items by assigned numbers, grouping and classification of items, and development of Navy Stock Lists, Federal Stock Numbers, and Coded Federal Stock Numbers have been discussed. The AQ will be using primarily the Coded Federal Stock Number, and when filling out a form requiring the stock number of an item, it is essential that the codes be included as they are an integral part of the number.

A typical number and its breakdown is as follows:



ACCOUNTING FOR SUPPLIES

Maintenance activities must stock and use many items of accountable material. The procedure to be followed in accounting and reporting accountable material is prescribed by the controlling activity. Although some control activities may have special requirements, all control activities require periodic inventories on all accountable material.

Inventories

An inventory is the process of counting and recording the actual quantities of material on hand. Its primary purpose is to bring quantities shown on stock records into balance with actual quantities on hand. It also provides a basis for correcting money value of the stock on hand.

The Aviation Fire Control Technician will be concerned primarily with inventorying fire control equipment, components, parts, and other associated equipment. However, whether prescribed locally or by the controlling authority, inventories provide a basis for:

1. Requisitioning material.
2. Accounting for use of material.
3. Disposition of excess material.

Controlling activities normally supply inventory forms specifically designed for reporting categories of equipments for which they have cognizance. A typical example is the Standard Aircraft Inventory Log.

STANDARD AIRCRAFT INVENTORY LOGS.—These logs are prepared by the Aviation Supply Office for each aircraft and are transferred with the aircraft. They contain a listing of all accessories, equipments, and components installed in the designated aircraft. However, the AQ will be concerned only with those components which pertain to fire control. Opposite each component two spaces are provided for making entries. The first column of spaces is used by the receiving activity for inventorying the aircraft prior to acceptance. The second column is used for inventorying the aircraft prior to transferring it to another activity.

DEPARTMENT OF DEFENSE AIRCRAFT INVENTORY RECORDS.—In the interest of standardization among the services, the Department of Defense instructed all services to prepare and utilize Aircraft Inventory Records, in lieu of Logs, for aircraft produced after mid 1955. It includes a sectional breakdown diagram of the applicable aircraft. This diagram consists of a side elevation and/or the plan view of a wing. To facilitate inventorying, the sections of the diagram are identified by letters, the letter "A" being assigned to the foremost section, "B" to the next, and so on, generally to the rear of the aircraft.

The equipment list portion of the Record is divided into sections, each of which lists the items pertaining to a particular section of the aircraft, as indicated on the sectional breakdown diagram. Within each section, individual items are numbered as nearly as possible in the sequence of their physical location in the aircraft without regard to their relation to specific equipment. Blank columns are provided on the inventory pages in a manner similar to that used in the Logs.

Accountability Code

In the preceding paragraphs, inventory of material has been discussed. However, the level of accountability for all material is not the same. This level is established by the Accountability Code published by the Bureau of Aeronautics. This code is a readily accessible guide for the maintenance man and will always be found in allowance lists and in the stock number data section of the Navy Stock List of the Aviation Supply Office. In the allowance lists the code letter will be found following each item listed. Also it will be found stamped on the nameplates of serialized components. The Accountability Code is also a valuable guide for use in:

1. Requisitioning material.
2. Accounting for material in use.
3. Disposing of material (turn-in).
4. Processing material for repair or overhaul.
5. Accounting for lost items.

The Accountability Code is as follows:

1. "A" Items—Plant property.
2. "O" Items—Repairable plant property.
3. "E" Items—Equipage. These items are maintained on a custodial signature basis and will be surveyed when lost or missing.

4. "R" Items—Repairable. These items are not issued for replacement without a turn-in of the replaced item. However, it may be drawn for initial installation without a turn-in.

5. "D" Items—Disposal. These items are technical aviation material and are not issued for replacement purposes without a turn-in of the replaced item.

6. "C" Items—Consumable. These items are considered expendable or consumed in use, and are issued without a turn-in of the replaced item.

NOTE: "O" and "A" items contain no aviation fire control equipment. Therefore, their description is in general terminology.

The Accountability Code just covered is the latest promulgated by the Bureau of Aeronautics effective 25 July 1957. It replaced or superseded the code in effect at that time. However, the following is a conversion chart for accountability code designations:

New code	*Old code*
"A"	"A"
"O"	"A"
"E"	"AX"
"R"	"X"
"D"	None
"C"	"C"

REPORTS

The Navy Department's ability to function as an efficient organization depends, in part, on it being able to maintain close contact with the operating units. This contact for aviation matters is handled by the Bureau of Aeronautics. It, in turn, has established a system of reports that are used to transmit various types of data to the bureau. However, the AQ2 will be primarily interested in those reports that pertain to the maintenance of aviation fire control equipments. Reports to be discussed in this chapter are surveys, maintenance usage data, and failure reports. Each will be discussed in detail in the paragraphs that follow.

Surveys

A SURVEY is the procedure required when an accountable item must be expended from the records due to loss, damage, deterioration, or normal wear. The survey request provides a record showing the cause, condition, responsibility, recommendation for disposition, and authority to expend material from the records. The custodian of the item to be surveyed prepares a rough copy of the Request for Survey (S. and A. Form 154), listing the cause and condition of the item to be surveyed.

There are two types of surveys—FORMAL and INFORMAL. A FORMAL SURVEY is required for those classes of material so designated by the bureau or office concerned or the commanding officer. The survey is conducted by either a commissioned officer or a board of three officers as appointed by the commanding officer. INFORMAL SURVEYS are conducted by the department head when directed by the commanding officer.

After the material has been surveyed, the survey is submitted to the commanding officer for approval. If approved, it is forwarded to the supply officer for disposition.

When a person in the naval service is found to be culpably responsible for actions necessitating a survey, he will be contacted by the surveying officer for a statement. The surveying officer must then recommend disciplinary action as the circumstances required. A note of such action will be made on the survey report and the Chief of the Bureau of Naval Personnel notified of the disciplinary action taken.

Maintenance Usage Data

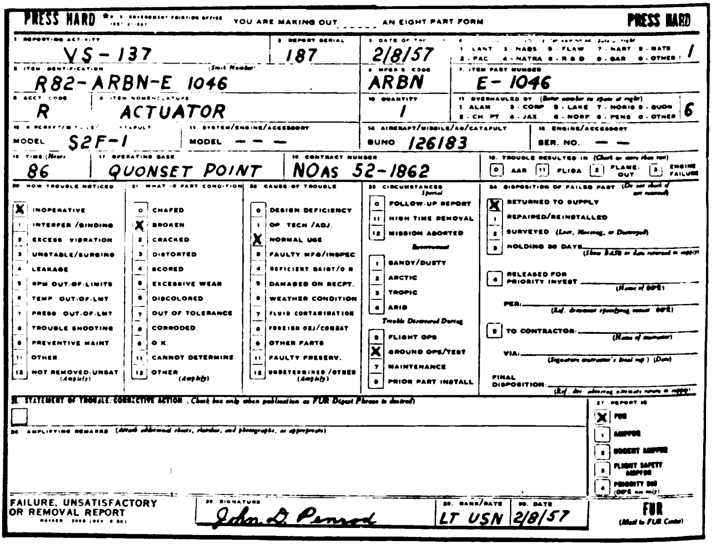
The Aviation Supply Office has established a procedure to be used by specifically designated maintenance activities in reporting material usage. The purpose of reporting this data is to provide a basis for computing amounts of maintenance material that must be purchased and made available for maintenance. It also provides data that is used in determining quantities of items allowed by the allowance list for each organization.

The maintenance usage data report lists the quantity of parts, subassemblies, or assemblies actually removed during a reporting period because of unsatisfactory operation; and for which a replacement was required. When subassemblies or assemblies are repaired locally, usage reported should not indicate usage of the subassembly or assembly, but should indicate only the parts utilized in effecting the repair. Reports of assemblies or subassemblies used should cover only those sent to overhaul.

Failure Reports

The failure of any component, subassembly, or assembly in an aviation fire control equipment must be reported to the Bureau of Aeronautics. All maintenance activities are supplied two different types of report forms for reporting failures. They are the Failure, Unsatisfactory or Removal Report (FUR Form NavAer 3069, Rev. 8–56), and Electronic Failure Report (EFR Form DD 787).

The FUR form is normally used when replacement of an



PRESS HARD YOU ARE MAKING OUT ______ AN EIGHT PART FORM **PRESS HARD**

1. REPORTING ACTIVITY: VS-137
2. REPORT SERIAL: 187
3. DATE OF [illegible]: 2/8/57
4. 1 LANT 3 NABS 5 FLAW 7 MART 9 MATS / 2 PAC 4 NATRA 6 R&D 8 BAR 0 OTHER: 1
5. ITEM IDENTIFICATION (Stock Number): R82-ARBN-E 1046
6. MFGR'S CODE: ARBN
7. ITEM PART NUMBER: E-1046
8. ACCT CODE: R
9. ITEM NOMENCLATURE: ACTUATOR
10. QUANTITY: 1
11. OVERHAULED BY (Enter number in space at right) 1 ALAM 3 CORP 5 LAKE 7 NORIS 9 QUON / 2 CH PT 4 JAX 6 NORF 8 PENS 0 OTHER: 6
12. AIRCRAFT/MISSILE/CATAPULT MODEL: S2F-1
13. SYSTEM/ENGINE/ACCESSORY MODEL: — — —
14. AIRCRAFT/MISSILE/AG/CATAPULT BUNO: 126183
15. ENGINE/ACCESSORY SER. NO.: — —
16. TIME (Hours): 86
17. OPERATING BASE: QUONSET POINT
18. CONTRACT NUMBER: NOAS 52-1862
19. TROUBLE RESULTED IN (Check no more than two): ☐ 0 AAR ☐ 11 FLIGA ☐ 2 FLAME-OUT ☐ 3 ENGINE FAILURE

20. HOW TROUBLE NOTICED
- ☒ INOPERATIVE
- ☐ 1 INTERFER /BINDING
- ☐ 2 EXCESS VIBRATION
- ☐ 3 UNSTABLE/SURGING
- ☐ 4 LEAKAGE
- ☐ 5 RPM OUT-OF-LIMITS
- ☐ 6 TEMP OUT-OF-LMT
- ☐ 7 PRESS OUT-OF-LMT
- ☐ 8 TROUBLE SHOOTING
- ☐ 9 PREVENTIVE MAINT
- ☐ 11 OTHER
- ☐ 12 NOT REMOVED-UNSAT (Amplify)

21. WHAT IS PART CONDITION
- ☐ 0 CHAFED
- ☒ BROKEN
- ☐ 2 CRACKED
- ☐ 3 DISTORTED
- ☐ 4 SCORED
- ☐ 5 EXCESSIVE WEAR
- ☐ 6 DISCOLORED
- ☐ 7 OUT OF TOLERANCE
- ☐ 8 CORRODED
- ☐ 9 O.K.
- ☐ 11 CANNOT DETERMINE
- ☐ 12 OTHER (Amplify)

22. CAUSE OF TROUBLE
- ☐ 0 DESIGN DEFICIENCY
- ☐ 1 OP TECH /ADJ.
- ☒ NORMAL USE
- ☐ 3 FAULTY MFG/INSPEC
- ☐ 4 DEFICIENT MAINT/O.H.
- ☐ 5 DAMAGED ON RECPT.
- ☐ 6 WEATHER CONDITION
- ☐ 7 FLUID CONTAMINATION
- ☐ 8 FOREIGN OBJ/COMBAT
- ☐ 9 OTHER PARTS
- ☐ 11 FAULTY PRESERV.
- ☐ 12 UNDETERMINED /OTHER (Amplify)

23. CIRCUMSTANCES
Special
- ☐ 0 FOLLOW-UP REPORT
- ☐ 11 HIGH TIME REMOVAL
- ☐ 12 MISSION ABORTED

Environment
- ☐ 1 SANDY/DUSTY
- ☐ 2 ARCTIC
- ☐ 3 TROPIC
- ☐ 4 ARID

Trouble Discovered During
- ☐ 5 FLIGHT OPS
- ☒ GROUND OPS/TEST
- ☐ 7 MAINTENANCE
- ☐ 8 PRIOR PART INSTALL

24. DISPOSITION OF FAILED PART (Do not check if not removed)
- ☒ RETURNED TO SUPPLY
- ☐ 1 REPAIRED/REINSTALLED
- ☐ 2 SURVEYED (Lost, Missing, or Destroyed)
- ☐ 3 HOLDING 30 DAYS ______ (Show BASD or date returned to supply)
- ☐ 4 RELEASED FOR PRIORITY INVEST ______ (Name of [illegible])

PER: ______ (Ref. document specifying [illegible])

- ☐ 5 TO CONTRACTOR: ______ (Name of contractor)

VIA: ______ (Signature contractor's local rep.) (Date)

FINAL DISPOSITION: ______ (Ref. doc. [illegible] to supply)

25. STATEMENT OF TROUBLE/CORRECTIVE ACTION (Check box only when publication as FUR Digest Phrase is desired) ☐

26. AMPLIFYING REMARKS (Attach additional sheets, sketches, and photographs, as appropriate)

27. REPORT IS
- ☒ FUR
- ☐ 1 AMPFUR
- ☐ 2 URGENT AMPFUR
- ☐ 3 FLIGHT SAFETY AMPFUR
- ☐ 4 PRIORITY DIS ([illegible] use only)

FAILURE, UNSATISFACTORY OR REMOVAL REPORT
NAVAER 3069 (REV. 8-56)

28. SIGNATURE: John D. Penrod
29. RANK/RATE: LT USN
30. DATE: 2/8/57

FUR (Mail to FUR Center)

Figure 13–2.—FUR (NavAer 3069, Rev. 8–56).

accountable subassembly, assembly, or component is required. It is also used to report failure of all mechanical components regardless of their accountability.

The EFR is generally used to report all routine electronic and electrical failures in which a component, subassembly, assembly, or equipment is repaired locally by replacement of a consumable electronic or electrical component. NOTE: The EFR is made out on the defective component and not the unit in which it was installed. The FUR is illustrated in figure 13–2.

The FUR provides for the below listed items of information which are required for analysis. Whenever possible, information should be obtained from the sources noted. Reports should be filled in by typewriter or ballpoint pen to insure good copies.

FUR's.—To execute a FUR report, entries on the NavAer 3069 will be completed as follows:

Space 1. REPORTING ACTIVITY—Insert authorized activity designation, i.e., FASRon 21, VA–116, FAWTULANT, NAS Alameda, etc.

Space 2. REPORT SERIAL—Each reporting activity will assign serial numbers to reports, starting with serial 1 at the beginning of each calendar year and progressing through serial 999. When reports from any activity exceed 999, then the serial will recommence with serial 1. This cycling will be repeated as often as necessary during the calendar year. Naval air stations, where several disassociated activities are located, should designate a specific block of numbers for use by each activity. These will be recycled as often as necessary. In no case will serial numbers exceeding 999 be used. Serial numbers should not have calendar year suffix added; i.e., serial number should be 123, not 123–57. ALPHABETIC CHARACTERS ARE NOT TO BE USED IN ANY REPORT SERIAL.

Space 3. DATE OF TROUBLE—Insert date fault or failure was actually encountered or found.

Space 4. MAJOR COMMAND—Insert appropriate number in space at right.

Space 5. ITEM IDENTIFICATION—Insert correct stock number as obtained from catalogs or handbooks. It is extremely important to the report processing that correct and complete stock number be reported.

Space 6. MANUFACTURER'S CODE—Insert the correct code for the contractor or manufacturer of the deficient part. Correct codes may be obtained from the nameplate of the part or assembly in which failure occurred, from the *Illustrated Parts Catalog*, or from the Navy Stock List of the Aviation Supply Office.

Space 7. ITEM PART NUMBER—Insert the manufacturer's part number as obtained from the nameplate or otherwise appearing on the failed part. If no part number is affixed, leave this space blank.

Space 8. ACCOUNTABILITY CODE—Insert proper material accountability code as appropriate.

Space 9. ITEM NOMENCLATURE—Insert noun name of part or assembly in which failure occurred; i.e., computer, synchronizer, modulator, etc.

Space 10. QUANTITY—Insert quantity of the deficient part replaced on a specific aircraft, or received from supply.

Space 11. OVERHAULED BY—Insert the appropriate overhaul activity code number in the space to the right. Overhaul activity may be determined from the decal or stamp on the part itself, or from logbook or accessory record cards. This space must be completed when item is known to have been overhauled. Do NOT complete if item has not been overhauled.

Space 12. AIRCRAFT/MISSILE/ARRESTING GEAR/CATAPULT MODEL—Insert the correct model such as F9F–6, AAM–N2, Mk 7, Mod 0, etc., in which the failure or malfunction occurred.

Space 13. SYSTEM/ENGINE/ACCESSORY MODEL—Enter the system at fault in this space; i.e., ASB/1A, AERO–21B, AERO–19A, etc.

Space 14. AIRCRAFT/MISSILE/ARRESTING GEAR/CATAPULT BUREAU NUMBER—Insert the bureau number or the bureau assigned serial number in which the deficiency occurred. Do NOT enter locally assigned numbers.

Space 15. ENGINE/ACCESSORY NUMBER—Enter the serial number from the nameplate on the item in which failure or malfunction occurred. If engine is noted in space 13, insert engine serial number.

Space 16. TIME—Insert the time the failed or faulty item had been in service prior to failure, since new or overhauled. Reported time in service should be obtained from the applicable logbook or accessory record card. When this information is not available, a reasonably accurate estimate of time in service should be given based on aircraft or engine time, considering usage of the reported part in relation to aircraft or engine usage. If report concerns unsatisfactory material received from the supply system, enter R.F.I. THIS ENTRY MUST BE COMPLETED ON ALL REPORTS.

Space 17. OPERATING BASE—Insert the name or location of the base or ship from which the aircraft, missile, arresting gear, or catapult is operated at the time the failure occurred.

Space 18. CONTRACT NUMBER—Enter the contract number of the part or assembly in which failure occurred. This number may be obtained from the nameplate of the part or assembly, logbooks or accessory record cards, shipping boxes or cases, or shipping documents.

Space 19. TROUBLE RESULTED IN—Requires AMPFUR. Check one or two of the check boxes as applicable. Do not check more than two. When AAR or FLIGA is checked enter applicable AAR of FLIGA serial number in space 26 (Amplifying Remarks).

Space 20. HOW TROUBLE NOTICED—Check box best describing general indication of how the trouble was first noticed. Do not check more than one box. NOTE: If box eleven (11) or twelve (12) is checked, it is necessary that the report be designated an AMPFUR.

Space 21. WHAT IS PART CONDITION?—Check box which most appropriately describes the condition of the part failed or removed. Do not check more than one box. NOTE: If box eleven (11) or twelve (12) is checked, it is necessary that the report be designated an AMPFUR.

Space 22. CAUSE OF TROUBLE—Check box which most appropriately describes the suspected cause for the reported failure or removal. NOTE: When box twelve (12) is checked, the report must be designated an AMPFUR.

Space 23. CIRCUMSTANCES—Check no more than one box in each group under this heading appropriate to the reported discrepancy.

Space 24. DISPOSITION OF FAILED MATERIAL—Check one box to describe the action taken to account for the removed or failed part. Special instructions for this entry are as follows:

(a) When box 3, 4, or 5 is checked, the report must be designated an AMPFUR.

(b) When box 3 is checked, the entry "Show BASO or date returned to supply" will be completed on the file copy only, to complete the reporting activity's material accountability records.

(c) When box 4 is checked, complete both entries. If the part is released for O&R investigation by local arrangement due to proximity of a qualified Overhaul and Repair Department, and coordination with the cognizant BAMR has not been required, note the governing work request identification and date in the entry entitled "Ref. Document specifying investigating O&R." In all other cases, note the appropriate BAMR reference identification and date designating the Overhaul and Repair Department to perform the priority investigation.

(d) When box 5 is checked, note the name of the contractor to whom the material is being released and obtain the signature of the contractor's authorized representative on the FUR and FILE copies before submitting the report.

(e) The entry "Final Disposition" at the bottom of space 24 will be completed on the FILE copy only whenever box 4 or 5 is checked. To complete the reporting activity's material accountability, this entry should show the identification and date of the document advising the disposition of released material upon completion of the investigation.

Space 25. STATEMENT OF TROUBLE—Not required on FUR's.

Space 26. AMPLIFYING REMARKS—Not required on FUR's.

Space 27. REPORT IS—Check appropriate box. Under no circumstances shall a report containing entries in space 25 or 26 be submitted as a FUR.

Space 28. SIGNATURE—This space will contain the signature of the qualified person designated to review and approve the report.

Space 29. RANK/RATE—Insert appropriate rank or rate of the person approving the report.

Space 30. DATE—Enter the date the report is mailed.

AMPFUR's.—In addition to containing all the information required for the FUR, an AMPFUR report shall contain the following:

STATEMENT OF TROUBLE (Space 25).—A brief, concise statement of the difficulty experienced and whatever corrective action was employed; i.e., Open synchro stator winding—replaced synchro. The statement will be reviewed for publication in the tabulated section of the Reliability Digest only when the box to the left of this space is checked. Publication of the statement will be determined on the basis of general interest in the problem by all custodians of the aircraft or equipment in which the trouble was found.

AMPLIFYING REMARKS (Space 26).—Enter all available information concerning the circumstances of the failure or malfunction.

PRIORITY AMPFUR's.—When priority investigation or corrective action is required, the report will be designated as an URGENT or FLIGHT SAFETY AMPFUR, by checking box 2 or 3 in space 27. The election of a priority category will at times be directed by BuAer, by major commands, or by local commanders. In other cases, the election of a priority report will be the result of the reporting activity's operational needs or of a Flight Safety occurrence. The first known instance of a failure or malfunction need not result in priority report submission. In such instances, however, an URGENT AMPFUR may be submitted and the material retained for 30 days. The following criteria are suggested for priority report submission:

1. URGENT AMPFUR

a. Flight safety is not involved.

b. Aircraft availability is seriously impaired for assigned mission as a result of a particular material deficiency.

c. Major material deficiencies are experienced on newly assigned aircraft, or on new production aircraft.

d. No indication of corrective action being taken on previously reported failures or malfunctions in which excessive maintenance time is required. Activities should insure such problems have not been reviewed in the Reliability Digest prior to report submission.

e. Unusual occurrences of material failures for which the cause cannot be determined.

2. FLIGHT SAFETY AMPFUR

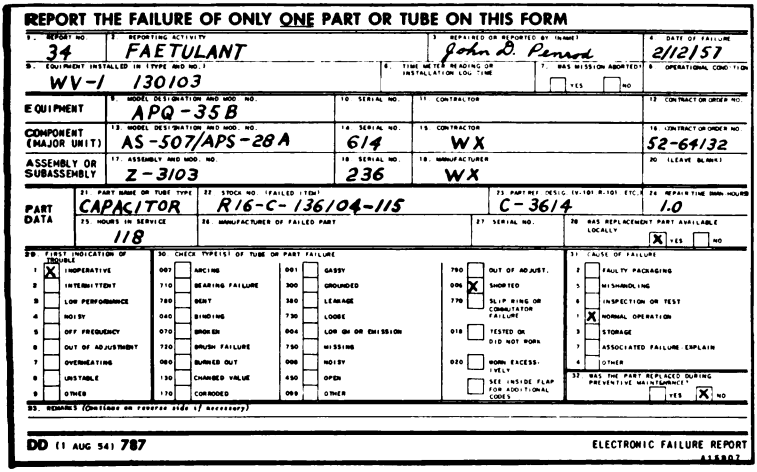
a. Failure or malfunction is the primary cause of an aircraft accident, forced landing, or incident.

b. The primary cause of an accident or incident is undetermined, but a material deficiency was involved.

c. Any other occurrence involving material deficiencies which in the opinion of the commanding officer involves flight safety.

EFR.—The entries on the EFR as illustrated in fig. 13–3 will be completed as follows:

Space 1. REPORT NUMBER.—Each reporting activity will assign serial numbers to reports, starting with serial 1 at the beginning of each calendar year and progressing through serial 999. When reports from any activity exceed 999, the serials recommence with serial 1 and this cycling will be repeated as often as necessary during the calendar year. In no case will serial numbers exceeding 999 be used. Serial number should be 123, not 123–57.



REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

1. REPORT NO.: 34
2. REPORTING ACTIVITY: FAETULANT
3. REPAIRED OR REPORTED BY (NAME): John D. Penrod
4. DATE OF FAILURE: 2/12/57
5. EQUIPMENT INSTALLED IN (TYPE AND NO.): WV-1 130103
6. TIME METER READING OR INSTALLATION LOG TIME:
7. WAS MISSION ABORTED? ☐ YES ☐ NO
8. OPERATIONAL CONDITION:

EQUIPMENT
9. MODEL DESIGNATION AND MOD. NO.: APQ-35B
10. SERIAL NO.:
11. CONTRACTOR:
12. CONTRACT OR ORDER NO.:

COMPONENT (MAJOR UNIT)
13. MODEL DESIGNATION AND MOD. NO.: AS-507/APS-28A
14. SERIAL NO.: 614
15. CONTRACTOR: WX
16. CONTRACT OR ORDER NO.: 52-64132

ASSEMBLY OR SUBASSEMBLY
17. ASSEMBLY AND MOD. NO.: Z-3103
18. SERIAL NO.: 236
19. MANUFACTURER: WX
20. (LEAVE BLANK)

PART DATA
21. PART NAME OR TUBE TYPE: CAPACITOR
22. STOCK NO. (FAILED ITEM): R16-C-136104-115
23. PART REF. DESIG. (V-101, R-101, ETC.): C-3614
24. REPAIR TIME (MAN-HOURS): 1.0
25. HOURS IN SERVICE: 118
26. MANUFACTURER OF FAILED PART:
27. SERIAL NO.:
28. WAS REPLACEMENT PART AVAILABLE LOCALLY ☒ YES ☐ NO

29. FIRST INDICATION OF TROUBLE
1 ☒ INOPERATIVE
2 ☐ INTERMITTENT
3 ☐ LOW PERFORMANCE
4 ☐ NOISY
5 ☐ OFF FREQUENCY
6 ☐ OUT OF ADJUSTMENT
7 ☐ OVERHEATING
8 ☐ UNSTABLE
9 ☐ OTHER

30. CHECK TYPE(S) OF TUBE OR PART FAILURE
007 ☐ ARCING
710 ☐ BEARING FAILURE
780 ☐ BENT
040 ☐ BINDING
070 ☐ BROKEN
720 ☐ BRUSH FAILURE
080 ☐ BURNED OUT
130 ☐ CHANGED VALUE
170 ☐ CORRODED
001 ☐ GASSY
300 ☐ GROUNDED
380 ☐ LEAKAGE
730 ☐ LOOSE
004 ☐ LOW GM OR EMISSION
750 ☐ MISSING
008 ☐ NOISY
450 ☐ OPEN
099 ☐ OTHER
790 ☐ OUT OF ADJUST.
006 ☒ SHORTED
770 ☐ SLIP RING OR COMMUTATOR FAILURE
018 ☐ TESTED OK DID NOT WORK
020 ☐ WORN EXCESSIVELY
☐ SEE INSIDE FLAP FOR ADDITIONAL CODES

31. CAUSE OF FAILURE
2 ☐ FAULTY PACKAGING
5 ☐ MISHANDLING
6 ☐ INSPECTION OR TEST
1 ☒ NORMAL OPERATION
3 ☐ STORAGE
7 ☐ ASSOCIATED FAILURE-EXPLAIN
4 ☐ OTHER

32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE? ☐ YES ☒ NO

33. REMARKS (Continue on reverse side if necessary)

DD (1 AUG 54) **787**

ELECTRONIC FAILURE REPORT

Figure 13–3.—Electronic Failure Report DD 787.

Detachments or units of a squadron will assign serial numbers independently of the parent squadron. No ALPHABETIC CHARACTERS WILL BE USED IN ANY REPORT SERIAL NUMBER.

Space 2. REPORTING ACTIVITY.—Enter the activity originating the report which is normally the activity performing the maintenance or investigation, or the custodian of the item reported at the time of the occasion for the report. Abbreviated administrative titles without prefixes shall be used, i.e., VF–12, VA–55, VC–3, VU–6, VX–4, FAETUPAC, Midway, Pt. Mugu, Alameda, etc. Squadron detachments or units should use the parent squadron number and the detachment number or letter, as VAH–2, "Mike."

Space 3. REPAIRED OR REPORTED BY.—The EFR should be signed by the person actually finding the trouble, or performing the maintenance or repair. Local procedures will be established for the review of EFR's by competent authority prior to submission.

Space 4. DATE OF FAILURE.—Insert date fault or failure was actually reported, or found.

Space 5. EQUIPMENT INSTALLED IN (TYPE AND NO.).—Insert the model AND the bureau number of the aircraft or missile in which the fault or failure occurred. When fault or failure is found during bench check of the equipment insert the word "Bench." Squadron aircraft numbers may not be used in lieu of the official bureau number.

Spaces 6, 7, and 8 are not used by naval aeronautical activities.

Space 9. (EQUIPMENT) MODEL DESIGNATION AND MOD NUMBER.—Insert the recognized designation of the system or equipment in which the failure occurred, i.e. ASB/1A, Aero–21B, Aero–19A, etc.

Space 10. SERIAL NUMBER.—This space will be used only when the equipment noted above is a self-contained unit. When the failure occurs in a component of an equipment, space 14 will be used.

Space 11. CONTRACTOR.—When the equipment noted in space 9 is a self-contained unit, enter the proper code for the manufacturer.

Space 12. CONTRACT NUMBER.—Complete only when the equipment in space 9 is a self-contained unit.

Space 13. (COMPONENT) MODEL DESIGNATION AND MOD NUMBER.—This entry is the one most commonly used in failure studies and will be used in preference to space 9 when the failure occurs in any component of an equipment. Entry will include complete designation, i.e., CP66A/ASB–1A, ID–295/APG–30 etc.

Space 14. SERIAL NUMBER.—Enter the serial number of the component (black box) in which failed part is located, as obtained from the nameplate.

Space 15. CONTRACTOR.—Enter the code letters for the manufacturer of the component in which failed part is located. This code is usually found on the nameplate or may be found in applicable handbooks, or by reference to *Aviation Supply Office Catalog* Section 0003 when the manufacturer's name is known, or in the coded federal stock number.

Space 16. CONTRACT NUMBER.—Enter the contract or order number for the component in which failure occurred, when such information is available from the nameplate or other sources.

Space 17, 18, 19, and 20.—Use only when applicable. Information required is similar to that required for a component and will be furnished only when a subassembly is specifically identified by these entries.

Space 21. PART NAME OR TUBE TYPE.—Enter the recognized noun name of the failed part (capacitor, resistor, motor, tube, etc.), and the tube type for tube failures (i. e., tube 6AK5, tube 5080, etc.). If a complete subassembly is replaced, enter the type, such as I.F. amplifier, spectrum amplifier, indicator, etc.

Space 22. STOCK NUMBER.—Enter correct stock number OF THE FAILED PART as obtained from Navy Stock List of the Aviation Supply Office Section "R" Allowance Lists, or applicable equipment handbooks.

Space 23. PART REF. DESIGNATOR.—Enter the part reference designator (symbol number) of the part failing, i.e., B–101, C–101, R–101, V–101, etc., as determined from the circuit diagram of handbooks for the pertinent equipment. Certain subassemblies may have no part reference designator, such as subassemblies for AN/ARC–27 equipment, and are identified only as 100–200, 400–600, etc., and in these cases record the complete group number (100–200).

Space 24. REPAIR TIME.—Enter the actual time required to isolate and repair the trouble reported. This time should be noted for the isolation and replacement of a single part. Where several parts contribute to an equipment failure and separate reports are submitted, the time for replacing each item should be calculated separately.

Space 25. HOURS IN SERVICE.—Enter the best available operating time on the item since new or overhauled. If elapsed time meters are not installed and no maintenance records are available, enter a reasonably accurate estimate of time in service using aircraft log time and considering operational requirements of the equipment in service. THIS ENTRY MUST BE COMPLETED ON EACH EFR.

Space 26. MANUFACTURER OF FAILED PART.—When available enter the code for the manufacturer of the failed part. Many parts of an electronic assembly are not identified by manufacturer due to size, and no effort should be expended to search for this information. Reports concerning electron tubes should always contain this entry. Correct codes are contained in the cross-reference section of the Navy Stock List of the Aviation Supply Office.

Space 27. SERIAL NUMBER.—This space should only be completed when the failed part contains a serial number, as may be found on certain magnetrons and klystrons.

Space 28. WAS REPLACEMENT PART AVAILABLE LOCALLY? —Check YES if replacement part was available in shop stores or in local supply stocks, otherwise check NO.

Space 29. FIRST INDICATION OF TROUBLE.—Check the ONE box which most appropriately describes the first indication of a fault or failure.

Space 30. CHECK TYPE OF PART FAILURE.—Check the ONE box which most appropriately describes the real or suspected condition of the part replaced.

Space 31. CAUSE OF FAILURE.—Check ONE box most descriptive of the cause for the part failing.

Space 32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE?—Check as appropriate.

Space 33. REMARKS.—Enter all available historical or engineering comments when such are available. The inclusion of such information will be of assistance in the evaluation of reports. Comments may be continued on the reverse of the form or on separate sheets of bond paper and attached to the report. Photographs (8 x 10 inch glossy finish), drawings, or sketches should be attached to the EFR when such matter will assist in determining the areas or cause of failure.

STORING MATERIAL AND SPARE PARTS

The task of requisitioning and receiving aviation supplies by an activity does not end the supply problem. The material is usually delivered from the supply point to the material officer of the maintenance or requesting activity. The material office then delivers it to the department originating the request. It then becomes the problem of the department to store and care for the material until ready for use. The accumulation of this material for maintenance necessitates the use of a storeroom.

Storerooms should be arranged to permit maximum storage capacity, access to all stores, orderly arrangement, security, and safety. There are a number of factors you must consider when setting up or maintaining a storeroom. The types and quantities of stores to be carried, rate of turnover, and points of use, should all play an important part in your planning.

The following is a list of suggestions to consider in establishing and operating a storeroom:

1. Arrange material in a neat and orderly fashion allowing accessibility to all stores.
2. Identify all items with their federal stock numbers and condition status.
3. Stow material so that fire fighting equipment can be readily used.
4. Keep storeroom clear of oily rags and other combustibles.
5. Handle all stock with care, keeping a close check on material requiring special handling.
6. Notify the department head when deterioration is discovered.

Efficient operation of a storeroom will do much to facilitate maintenance of aviation fire control equipment.

QUIZ

1. The Aviation Supply Office operates under the joint authority of
   a. BuSandA and BuShips
   b. BuSandA and BuOrd
   c. BuSandA and BuAer
   d. BuAer and BuOrd
2. The categories of material purchased and distributed by ASO are controlled by the
   a. Bureau of Aeronautics
   b. Bureau of Supplies and Accounts
   c. Aviation Supply Office
   d. fleet commands
3. ASO estimates of material requirements are based on the naval aircraft program, operational plans of the Navy Department, and
   a. inventory control of aeronautical equipment
   b. fleet recommendations
   c. usage data reports
   d. appropriated funds
4. Inventory control of aeronautical material is a function of the
   a. Bureau of Aeronautics
   b. Aviation Supply Office
   c. FASRon
   d. commanding officer
5. The cognizance control symbol for the Bureau of Ordnance is
   a. N
   b. R
   c. Z
   d. J
6. Storehouse facilities for bulk storage of aeronautical material are maintained by
   a. distribution stock points
   b. primary stock points
   c. secondary stock points
   d. reserve stock points

7. Nonreporting units carrying stock for their own consumption and assigned aircraft are designated
   a. primary stock points
   b. secondary stock points
   c. satellites
   d. distribution stock points

8. Satellites are furnished complete aeronautical supply support by
   a. reserve stock points
   b. distribution stock points
   c. primary stock points
   d. secondary stock points

9. Charges and credits to appropriations are reported to the
   a. Bureau of Supplies and Accounts
   b. Aviation Supply Office
   c. Bureau of Aeronautics
   d. Congress of the United States

10. The BuAer allowance list having the section K designator concerns
   a. shop-handling and servicing equipment
   b. aviation fire control equipment
   c. aeronautical electronics material
   d. naval aeronautics publications and forms

11. All items of federal stock are identified and cataloged by the
   a. Bureau of Supplies and Accounts
   b. Department of Defense
   c. cognizant bureau
   d. Munitions Board for the Federal Government

12. What section of the Navy Stock List of the Aviation Supply Office contains the unit price, the unit of issue, and the accountability code of a specific item?
   a. Stock number data section
   b. Cross-reference section
   c. Descriptive section
   d. Parts list section

13. The first two digits of the Federal Stock Number indicate the
   a. class code number
   b. stock group
   c. cognizant bureau
   d. class breakdown

14. What part of the Navy Stock List of the Aviation Supply Office is published in weekly segments and is completely revised quarterly to show an up-to-date availability?
    a. Federal number section
    b. Stock number data section
    c. Cross reference section
    d. Descriptive section

15. In the stock number R F B 1630–123–4567–F WXE, "WXE" indicates the
    a. Cognizance Symbol
    b. Fraction Code
    c. manufacturer
    d. Material Condition Code

16. The procedure to be followed in accounting and reporting accountable material is prescribed by
    a. the controlling activity
    b. ASO
    c. BuAer
    d. NavAer 00–500

17. What allowance list section is used to determine the amount of tools that are to be issued to a new shop being placed in a ready condition?
    a. Section A
    b. Section R
    c. Section O
    d. Section U

18. Where can the Accountability Code for fire control equipment be found?
    a. Allowance list for the specific equipment
    b. Navy Stock Cross-Reference List
    c. Standard Aircraft Inventory Log
    d. Overhaul instruction manual

19. Material having an accountability code of "A" is
    a. plant property
    b. repairable
    c. consumable
    d. issued without a turn-in of the replaced item

20. The publication listing all accessories, equipments, and components installed in the designated aircraft is known as the
    a. Bureau of Aeronautics Allowance List
    b. *Naval Aeronautic Publications Index*
    c. Standard Aircraft Inventory Log
    d. Section "A" Allowance List

21. Informal surveys are conducted
    a. by department heads as directed by the commanding officer
    b. to investigate the circumstances before recommending a formal survey
    c. only when no disciplinary action is required
    d. when the monetary value of the equipment is less than one hundred dollars

22. The failure of any aviation fire control component must be reported to the
    a. Bureau of Ordnance
    b. ASO
    c. Bureau of Aeronautics
    d. contractor

23. Report serial numbers of FUR's
    a. start with serial #1 at the beginning of each fiscal year
    b. may contain alphabetic characters
    c. should never exceed 999
    d. should have the calendar year suffix added

24. When either box 2 or 3 in space 27 of the AMPFUR has been checked, the report has become a/an
    a. URGENT AMPFUR
    b. O&R overhaul request
    c. test equipment failure report
    d. flight safety report

25. If a defective resistor is replaced in a radar transmitter, a report would be made on a/an
    a. EFR
    b. FUR
    c. AMPFUR
    d. request for survey

26. The EFR should be signed by the
    a. division chief
    b. person finding the trouble
    c. crew leader
    d. storeroom personnel

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

INTRODUCTION TO AQ2

1. d.
2. c.
3. a.
4. d.
5. d.
6. b.
7. b.
8. d.
9. c.
10. b.

CHAPTER 2

ELECTRONIC TEST EQUIPMENT

1. a.
2. d.
3. c.
4. b.
5. a.
6. d.
7. a.
8. d.
9. b.
10. a.
11. b.
12. d.
13. a.
14. d.
15. c.
16. c.
17. d.
18. c.
19. a.
20. a.
21. d.
22. c.
23. c.
24. b.
25. c.
26. c.

CHAPTER 3

ELECTRONIC MAINTENANCE

1. d.
2. b.
3. a.
4. a.
5. b.
6. c.
7. a.
8. b.
9. c.
10. b.
11. a.
12. b.
13. c.
14. b.
15. c.
16. d.
17. c.
18. a.
19. d.
20. b.
21. c.
22. d.
23. b.
24. a.
25. c.

CHAPTER 4

MAGNETIC AMPLIFIERS

1. c.
2. a.
3. d.
4. d.
5. a.
6. d.
7. a.
8. a.
9. b.
10. c.
11. c.
12. d.
13. b.
14. d.
15. a.
16. b.
17. c.
18. d.
19. a.
20. c.

CHAPTER 5

SERVOMECHANISMS

1. b.
2. b.
3. d.
4. c.
5. d.
6. c.
7. a.
8. b.
9. c.
10. b.
11. c.
12. b.
13. d.
14. b.
15. d.
16. a.
17. b.
18. a.
19. d.
20. a.
21. b.

CHAPTER 6

TYPICAL AVIATION FIRE CONTROL SERVO SYSTEMS

1. b.
2. d.
3. a.
4. c.
5. b.
6. c.
7. a.
8. d.
9. b.
10. d.
11. c.
12. a.
13. c.
14. b.
15. d.
16. a.

CHAPTER 7

DATA SENSING DEVICES

1. a.
2. b.
3. d.
4. a.
5. c.
6. b.
7. c.
8. a.
9. b.
10. d.
11. c.
12. a.
13. b.
14. d.
15. c.
16. c.
17. b.
18. b.
19. c.
20. a.
21. a.
22. b.
23. b.
24. d.

CHAPTER 8

INTRODUCTION TO COMPUTERS

1. b.
2. d.
3. b.
4. a.
5. d.
6. d.
7. d.
8. c.
9. c.
10. a.
11. b.
12. a.
13. b.
14. c.

CHAPTER 9

COMPUTING INSTRUMENTS

1. b.
2. c.
3. a.
4. b.
5. b.
6. a.
7. d.
8. d.
9. a.
10. b.
11. c.
12. a.
13. d.
14. b.
15. a.
16. c.
17. c.
18. a.
19. b.
20. d.
21. a.
22. b.
23. b.
24. a.
25. d.
26. b.
27. d.

CHAPTER 10

ELECTROMAGNETIC COMPUTER

1. b.
2. c.
3. a.
4. b.
5. b.
6. d.
7. b.
8. d.
9. c.
10. a.
11. d.
12. c.
13. c.
14. a.
15. d.
16. d.
17. a.
18. a.
19. c.
20. d.
21. c.

CHAPTER 11

ELECTROMECHANICAL COMPUTER

1. b.
2. d.
3. a.
4. a.
5. c.
6. d.
7. d.
8. b.
9. a.
10. c.
11. a.
12. c.
13. b.
14. a.
15. a.
16. c.
17. d.
18. b.
19. d.
20. b.
21. a.
22. c.

CHAPTER 12

MECHANICAL COMPUTER

1. a.
2. a.
3. a.
4. a.
5. b.
6. d.
7. a.
8. c.
9. b.
10. d.
11. a.
12. c.
13. a.
14. d.
15. b.
16. c.
17. a.
18. a.
19. d.
20. c.
21. b.
22. d.
23. c.
24. b.

CHAPTER 13

MATERIAL AND SPARE PARTS

1. c.
2. a.
3. c.
4. b.
5. d.
6. d.
7. b.
8. c.
9. a.
10. d.
11. d.
12. a.
13. b.
14. b.
15. c.
16. a.
17. d.
18. a.
19. a.
20. c.
21. a.
22. c.
23. c.
24. a.
25. a.
26. b.

APPENDIX II

FIRE CONTROL SYMBOLS

GUNNERY AND ROCKET:

Symbol	*Definition*
R	Present range.
R_f	Future range.
T	Indicated temperature.
t_f	Time of flight of projectile.
t_fL	Lost time of flight.
V_G	Groundspeed.
V_O	Average projectile velocity.
V_m	Muzzle velocity.
V_A	True airspeed.
Λ	Total lead angle.
Λ_A	Azimuth component of total lead angle.
Λ_E	Elevation component of total lead angle.
Λ_b	Ballistic lead angle.
Λ_{bA}	Azimuth component of ballistic lead angle.
Λ_{bE}	Elevation component of ballistic lead angle.
Λ_k	Kinematic lead angle.
Λ_{kA}	Azimuth component of kinematic lead angle.
Λ_{kE}	Elevation component of kinematic lead angle.
Λ_{bW}	Windage factor of ballistic lead.
Λ_{bWE}	Elevation component of the windage factor.
Λ_{bWA}	Azimuth component of the windage factor.
Λ_{bG}	Gravity factor of ballistic lead.
Λ_{bGE}	Elevation component of gravity factor.
Λ_{bGA}	Azimuth component of gravity factor.
P	Antenna position.
P_A	Antenna position in azimuth.
P_E	Antenna position in elevation.
ω	Angular velocity.
ω_A	Angular velocity in azimuth.
ω_E	Angular velocity in elevation.
P_S	Static air pressure.
λ_o	Gravity drop factor.
A_A	Angle of attack.
A_S	Angle of skid.
A_L	Launcher angle.
T_R	Rocket propellant temperature.
R_o	Preset future range.

GUNNERY AND ROCKET—Continued

Symbol	*Definition*
D	Air density.
t	Time.
$1/t_f$	Inverse time of flight.
$\dot{R}$	Range rate.
E	Error term.
E_R	Range error term (range coil voltage).
E_E	Elevation error term (elevation coil voltage).
E_A	Azimuth error term (azimuth coil voltage).
E_H	Heading error.
E_{HE}	Heading error in elevation.
E_{HA}	Heading error in azimuth.
e_H	Steering error.
e_{HE}	Steering error in elevation.
e_{HA}	Steering error in azimuth.
a	Ballistic constant.
c	Ballistic constant.
T_d	Dome temperature.
N	Acceleration.
h	Ballistic constant (launching factor).
t_b	Rocket burn time.
V_b	Rocket burnt velocity.
V_0'	Velocity of projectile in vacuum.
ΔV_0	Decrease in velocity of projectile due to air drag.

BOMBING

Symbol	*Definition*
y	Magnetic variation.
θ	True heading.
θ_m	Magnetic heading.
θ_R	Relative bearing.
η	True course.
η_R	Relative course.
μ	True bearing.
V_W	Wind velocity.
${}_RV_W$	Range wind.
μV_W	Cross wind.
R	Horizontal range.
H_T	Target altitude above sea level.
H_A	Aim point altitude above sea level.
H_O	Aircraft altitude above sea level.
H	Aircraft altitude above aim point.

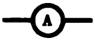
BOMBING—Continued

Symbol	*Definition*
V_H	Vertical velocity.
T	Ballistics.
S	Horizontal offset of target from aim point.
ψ	Angular position of S vector from true north.
P_V	Pitot air pressure.
T_s	Stagnation temperature.
r	Slant range.
ϕ	Elevation angle of line of sight.
V_R	Range rate.
V_μ	Azimuth rate.
R_0	Initial horizontal range.
t	Time.
k	Drift angle.
μ_0	Initial true bearing.
γ	Nonlinear V_G.
T'	Trail (in feet).
Δ	Change in a quantity when used as a prefix.
t_f	Time of fall.

APPENDIX III

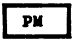
ELECTRONIC SYMBOLS

METERS.

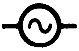


A - AMMETER
CRO - OSCILLOSCOPE
G - GALVANOMETER
MA - MILLIAMMETER
OHM - OHMMETER
V - VOLTMETER

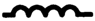
PERMANENT MAGNET



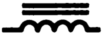
A-C SOURCE



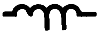
INDUCTORS



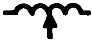
GENERAL



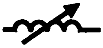
MAGNETIC CORE



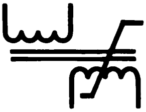
TAPPED



ADJUSTABLE

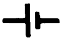


ADJUSTABLE OR CONTINUOUSLY ADJUSTABLE

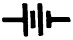


SATURABLE CORE REACTOR

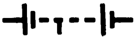
BATTERIES



ONE CELL



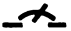
MULTICELL



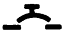
TAPPED MULTICELL

(LONG LINE IS ALWAYS POSITIVE)

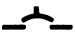
CIRCUIT BREAKERS



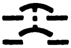
SWITCH



PUSH-PULL

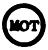


PUSH

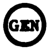


GANGED

MOTORS AND GENERATORS

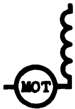


MOTOR

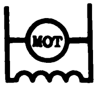


GENERATOR

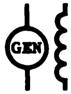
TYPES OF WINDINGS



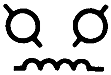
SERIES



SHUNT



SEPARATELY EXCITED



DYNAMOTOR

WINDING SYMBOLS

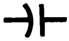
SINGLE-PHASE

TWO - PHASE

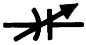
THREE-PHASE (WYE)

THREE-PHASE (DELTA)

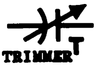
CAPACITORS



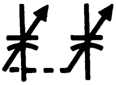
FIXED



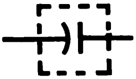
VARIABLE



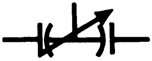
TRIMMER



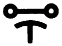
GANGED



SHIELDED



SPLIT-STATOR

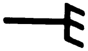


FEED-THROUGH

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

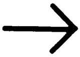
APPENDIX III—ELECTRONIC SYMBOLS—Continued

CHASSIS CONNECTION

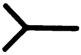


(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

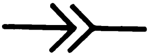
CONNECTORS



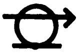
MALE
(PIN CONTACT)



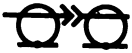
FEMALE
(SOCKET CONTACT)



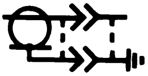
ENGAGED
(PIN-TO-SOCKET)



COAXIAL
(MALE)



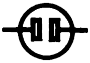
COAXIAL CONNECTORS
MATED



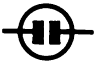
COAXIAL CONNECTED
TO SINGLE CONDUCTOR

THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.

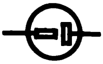
POWER CONNECTORS



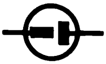
NON POLARIZED,
FEMALE CONTACTS
(2-CONDUCTOR)



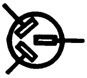
NON POLARIZED,
MALE CONTACTS
(2-CONDUCTOR)



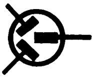
POLARIZED
FEMALE CONTACTS
(2-CONDUCTOR)



POLARIZED
MALE CONTACTS
(2-CONDUCTOR)

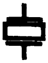


POLARIZED
FEMALE CONTACTS
(3-CONDUCTOR)



POLARIZED
MALE CONTACTS
(3-CONDUCTOR)

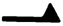
CRYSTAL UNIT



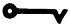
QUARTZ CRYSTAL; PIEZOELECTRIC CRYSTAL UNIT.

CONTACTS

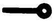
SWITCH



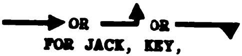
MOMENTARY
SWITCH



LOCKING

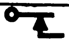


NONLOCKING

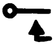


FOR JACK, KEY,
RELAY, ETC.

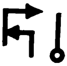
CONTACT ASSEMBLIES



CLOSED CONTACT
(BREAK)

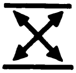


OPEN CONTACT
(MAKE)

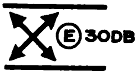


MAKE BEFORE
BREAK

COUPLERS, DIRECTIONAL



GENERAL

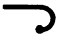


E PLANE APERTURE
COUPLING, 30 DB
TRANSMISSION LOSS

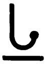
COUPLING

GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.

COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).

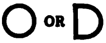


COUPLING BY LOOP TO SPACE

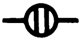


COUPLING BY LOOP TO GUIDED TRANSMISSION PATH

LIGHT, INDICATING



INDICATING, PILOT, SIGNALING OR SWITCHBOARD PILOT LIGHT, GENERAL.

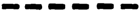


JEWELLED INDICATOR OR WARNING LIGHT.

THE LETTER L IS ADDED IN THE SYMBOL TO INDICATE LAMP.

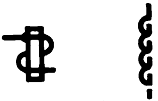
APPENDIX III—ELECTRONIC SYMBOLS—Continued

SHIELDING

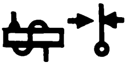


SHORT DASHES. NORMALLY USED FOR ELECTRIC OR MAGNETIC SHIELDING

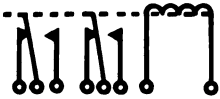
RELAYS



RELAY COIL (DOT INDICATES INNER END OF WINDING)

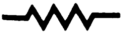


RELAY WITH TRANSFER CONTACTS (SPDT)

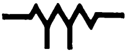


DOUBLE POLE, DOUBLE THROW (DPDT) RELAY

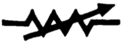
RESISTORS



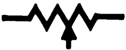
GENERAL



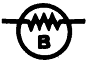
TAPPED



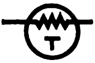
VARIABLE



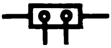
ADJUSTABLE



THERMAL (BALLAST LAMP)

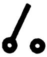


THERMAL (THERMISTOR)

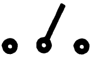


INSTRUMENT OR RELAY SHUNT

SWITCHES

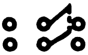


GENERAL (SINGLE THROW)

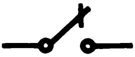


GENERAL (DOUBLE THROW)

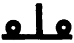
SWITCHES (CONT)



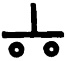
TWO-POLE DOUBLE-THROW SWITCH



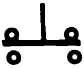
KNIFE SWITCH



PUSH BUTTON (BREAK)

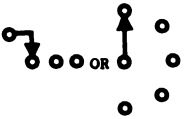


PUSH BUTTON (MAKE)



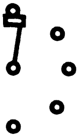
PUSH BUTTON TWO CIRCUIT

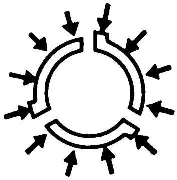
SELECTOR SWITCHES



GENERAL
ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK-BEFORE-MAKE SWITCH.

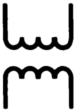
MAKE-BEFORE BREAK



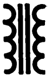


WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

TRANSFORMERS



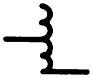
GENERAL



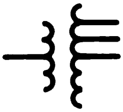
MAGNETIC CORE TRANSFORMER

APPENDIX III—ELECTRONIC SYMBOLS—Continued

TRANSFORMERS (CONT)

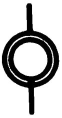


AUTOTRANSFORMER



WITH TAPS,
SINGLE-PHASE

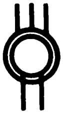
SYNCHROS



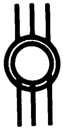
GENERAL

A LETTER COMBINATION FROM THE FOLLOWING LIST SHALL BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

- TX - TORQUE TRANSMITTER
- TDX - TORQUE DIFFERENTIAL TRANSMITTER
- CX - CONTROL TRANSMITTER
- CDX - CONTROL DIFFERENTIAL TRANSMITTER
- TR- TORQUE RECEIVER
- CT - CONTROL TRANSFORMER



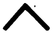
TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER



DIFFERENTIAL TRANSMITTER OR RECEIVER

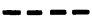
TUBES, ELECTRON

COMPONENT TUBE SYMBOLS

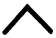


DIRECTLY-HEATED
(FILAMENTARY)
CATHODE

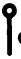
INDIRECTLY-HEATED
CATHODE



GRID



HEATER



COLD
CATHODE

ANODE OR
PLATE

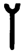
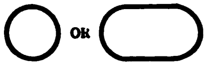
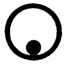


PHOTO CATHODE

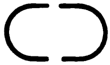
ELECTRON TUBES (CONT)



ENVELOPE (SHELL)

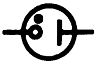


GAS FILLED
ENVELOPE

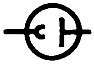


SPLIT ENVELOPE

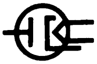
TYPICAL BUILDUP OF TUBE EXAMPLES



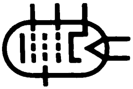
COLD CATHODE
GAS TUBE



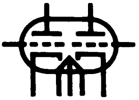
PHOTOTUBE SINGLE
UNIT, VACUUM



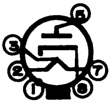
DIODE



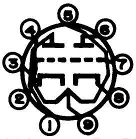
PENTODE



TWIN TRIODE
ILLUSTRATING
ELONGATED ENVELOPE

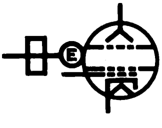


DIODE SHOWING BASE
CONNECTIONS



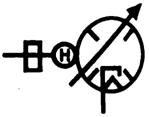
TWIN TRIODE WITH TAPPED HEATER

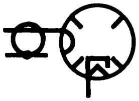
MAGNETRONS AND KLYSTRONS



REFLEX KLYSTRON,
APERTURE COUPLED

TUNEABLE MAGNETRON,
APERTURE COUPLED

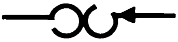




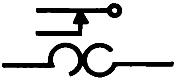
RESONANT TYPE WITH
COAXIAL OUTPUT

APPENDIX III—ELECTRONIC SYMBOLS—Continued

ELEMENT, THERMAL

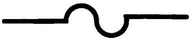


FLASHER; THERMAL CUTOUT

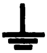


THERMAL RELAY WITH
NORMALLY CLOSED
CONTACT.

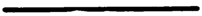
FUSE



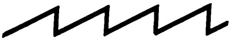
GROUND



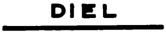
PATH, TRANSMISSION



CONDUCTOR OR
GROUP OF CONDUCTORS

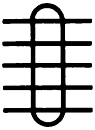


AIR OR SPACE PATH

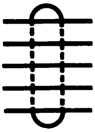


DIELECTRIC PATH
OTHER THAN AIR

CABLES

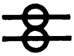


FIVE-CONDUCTOR
CABLE

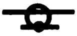


SHIELDED
FIVE-CONDUCTOR
CABLE

NUMBER OF CONDUCTORS MAY BE ONE
OR MORE AS NECESSARY

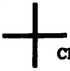


TWISTED PAIR

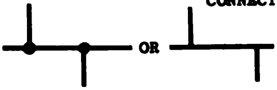


COAXIAL

PATH, TRANSMISSION (CONT)

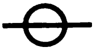


CROSSING NOT
CONNECTED

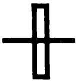


JUNCTION CONNECTED

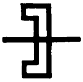
WAVEGUIDES



CIRCULAR

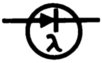


RECTANGULAR

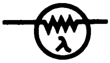


RIDGED

PHOTOELECTRIC CELLS

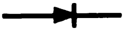


ASYMMETRICAL
PHOTOCONDUCTIVE TRANSDUCER
(RESISTIVE)



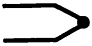
SELENIUM CELL

RECTIFIERS

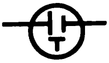


METALLIC RECTIFIER; ASYMMETRICAL VARISTOR; CRYSTAL DIODE; ELECTROLYTIC RECTIFIER. ARROW SHOWS DIRECTION OF FORWARD (EASY) CURRENT AS INDICATED BY D-C AMMETER.

THERMOCOUPLES



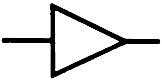
TEMPERATURE-MEASURING THERMOCOUPLE
(DISSIMILAR METAL DEVICE)



TEMPERATURE-MEASURING SEMICONDUCTOR
THERMOCOUPLE

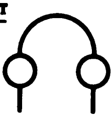
APPENDIX III—ELECTRONIC SYMBOLS—Continued

AMPLIFIER

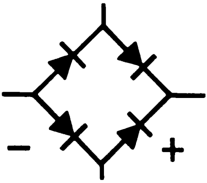


THE TRIANGLE IS POINTED IN THE DIRECTION OF TRANSMISSION

HEADSET

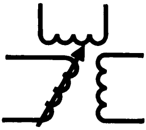


RECTIFIER

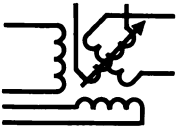


FULL WAVE BRIDGE TYPE

RESOLVER

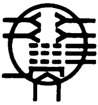


SINGLY-WOUND ROTOR

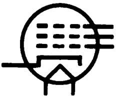


DOUBLY-WOUND ROTOR

CATHODE RAY TUBE

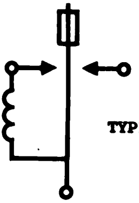


ELECTROSTATIC DEFLECTION

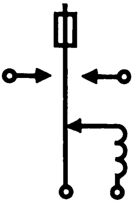


MAGNETIC DEFLECTION

VIBRATOR



TYPICAL, SHUNT DRIVE



TYPICAL, SEPARATE DRIVE

APPENDIX IV

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION FIRE CONTROL TECHNICIANS (AQ)

Rating Code No. 6520

(Through Change 11)

General Service Rating

Scope

Aviation Fire Control Technicians test, maintain, and repair aviation fire control equipment; inspect, clean, lubricate, and perform operational tests and adjustments of sights, bomb directors, armament control systems, and turret control systems; remove and reinstall major components and subassemblies; calibrate, repair, and make performance measurements and computing tests of computers, gyros, optical components, and fire control radars; make detailed mechanical, electrical, and electronic casualty analysis; boresight and aline sights, computers, fire control radars, and aircraft weapons; make authorized repairs and adjustments to associated test equipment.

Emergency Service Ratings

AVIATION FIRE CONTROL TECHNICIANS F (Aircraft Armament Control Systems), Rating Code No. 6522------------------------------ AQF

Test, maintain, and repair aviation fire control equipment (excluding bomb directors); inspect, clean, lubricate, and perform operational tests of optical gun sights, armament control systems, and turret control systems; remove and reinstall major components, assemblies, subassemblies, and detailed parts; calibrate, repair, and make performance measurements and computing tests of computers, gyros, optical components, and armament control radars; make detailed mechanical, electrical, and electronic casualty analysis; boresight and aline optical gunsights, computers, armament control radars, and aircraft weapons; make authorized repairs and adjustments to associated test equipment.

AVIATION FIRE CONTROL TECHNICIANS B (Bomb Director), Rating Code No. 6521-- AQB

Test, maintain, and repair bomb directors systems; inspect, clean, lubricate, and perform operational tests and adjustments of bomb director systems (including optical components thereof); remove and reinstall major components, assemblies, subassemblies, and detailed parts; calibrate, repair, and make performance measurements and computing tests of computers, gyros, optical components, and bomb director radars; make detailed mechanical, electrical, and electronic casualty analysis; boresight and aline sights, computers, and bomb director radars; make authorized repairs and adjustments to associated test equipment.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see *Manual of Navy Enlisted Classifications*, NavPers 15105 (Revised), codes AQ–7900 through AQ–7999.

Qualifications for Advancement in Rating

Qualifications for advancement in rating	*Applicable rates*		
	AQ	**AQF**	**AQB**
100 PRACTICAL FACTORS			
101 OPERATIONAL			
1. Demonstrate under simulated conditions the rescue of a person in contact with an energized electrical circuit, resuscitation of a person unconscious from electrical shock, and treatment for electrical burns	3	3	3
2. Energize, secure, set operating controls, make operator's adjustments and read and interpret dials, built-in meters, and cathode ray tube presentations on:			
*a. Aircraft armament control systems	3	3	--
*b. Bomb director systems	3	--	3
102 MAINTENANCE AND/OR REPAIR			
1. Select and use hand tools and small portable power tools provided for maintenance and repair of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
2. Make electrical connections and splices, including soldered joints	3	3	3

---

* Where terms "aircraft armament control systems" and "bomb director systems" are used in the qualifications items, these systems are defined in terms of the scopes of emergency service ratings.

Qualifications for advancement in rating	Applicable rates		
	AQ	AQF	AQB
102 MAINTENANCE AND/OR REPAIR—Continued			
3. Operate the following test equipment:			
a. Voltmeter	3	3	3
b. Ammeter	3	3	3
c. Ohmmeter	3	3	3
d. Multimeter	3	3	3
e. Megger	3	3	3
f. Tube tester	3	3	3
g. Oscilloscope	3	3	3
h. Vacuum tube voltmeter	3	3	3
4. Perform operational tests, make external adjustments and isolate casualties to major components of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
5. Test and replace relays, plugs, lamps, fuses, switches, electron tubes, jacks, cables, and wiring	3	3	3
6. Draw and interpret schematic diagrams of electrical circuits; read and interpret wiring diagrams of electrical circuits found in technical maintenance publications; identify electronic and mechanical symbols	3	3	3
7. Identify capacitors, resistors, and wiring by standard color coding systems	3	3	3
8. Test aviation fire control circuits for continuity, short circuits, and grounds between major components, and report results	3	3	3
9. Use block diagrams and mechanical drawings to locate and identify major components and subassemblies of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
10. Inspect and clean commutators and slip ring assemblies; inspect and replace brushes	3	3	3
11. Lubricate and clean components of the following systems in accordance with technical maintenance publications:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3

Qualifications for advancement in rating	*Applicable rates*		
	AQ	**AQF**	**AQB**
102 MAINTENANCE AND/OR REPAIR—Continued			
12. Remove, reinstall, inspect and test for correct installation major components and subassemblies of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
13. Boresight and aline aircraft sights of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
14. Operate the following test equipment:			
a. Signal generator	2	2	2
b. Frequency meter	2	2	2
c. Sweep generator	2	2	2
15. Perform tests, adjustments, and repairs necessary for proper operation of power supplies, including analysis of casualties in rectifiers, regulators, and filter circuits	2	2	2
16. Perform tests, adjustments, and repairs necessary for proper operation of electromechanical computers, including analysis of casualties in voltage amplifiers, power amplifiers, phase detectors, and amplitude modulators	2	2	2
17. Perform tests, adjustments, and repairs necessary for proper operation of electromechanical servo mechanisms and synchro circuits including:			
a. Zeroing of synchros, servomotors, and potentiometers	2	2	2
b. Gain, phase, and balancing adjustments	2	2	2
18. Test electronic and electromechanical computers for alinement; replace basic fire control mechanisms and circuit components; make alinement adjustments	2	2	2
19. Perform computing and rate tests of electronic and electromechanical computers, using calculated values and tolerances found in technical maintenance publications	2	2	2
20. Test and replace resistors, capacitors, inductors, plug-in units, potentiometers, synchros, servomotors, shafts, and gearing	2	2	2

Qualifications for advancement in rating	*rates Applicable*		
	AQ	**AQF**	**AQB**
102 MAINTENANCE AND/OR REPAIR—Continued			
21. Draw and interpret schematic diagrams of electronic circuits; read and interpret wiring diagrams of electronic circuits found in technical maintenance publications	2	2	2
22. Test aviation fire control electronic circuits for continuity, short circuits, and grounds; measure electrical quantities, such as voltage, current, power, frequency, and phase angle, and compare with established values; trace signals, using an oscilloscope; determine wave forms and compare with established or required forms	2	2	2
23. Effect field changes in accordance with instructions and diagrams to:			
a. Aircraft armament control systems	2	2	--
b. Bomb director systems	2	--	2
24. Operate the following test equipment:			
a. Range calibrator	1	1	1
b. Spectrum analyzer	1	1	1
c. RF wattmeter	1	1	1
d. Wavemeter	1	1	1
e. Echo box	1	1	1
25. Perform tests, adjustments, and repairs necessary for proper operation of radar components, including analysis of casualties in transmitters, receivers, synchronizers, modulators, indicators, and antenna systems, used in:			
a. Aircraft armament control systems	1	1	--
b. Bomb director systems	1	--	1
26. Make performance measurements, calibrations. and adjustments to bring to optimum performance:			
a. Complete airborne intercept and turret systems	1	1	--
b. Complete bombing systems	1	--	1
27. Boresight and aline fire control radars and optical devices associated with:			
a. Aircraft weapons	1	1	--
b. Bombing systems	1	--	1

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	**AQF**	**AQB**
102	MAINTENANCE AND/OR REPAIR—Continued			
	28. Determine proper operation of and replace klystrons, magnetrons, T/R and AT/R boxes, crystal mixers, wave guide sections, pressurizing systems, and antennas	1	1	1
	29. Lubricate and perform authorized adjustments to gyroscopes used in:			
	a. Aircraft armament control systems	1	1	--
	b. Bomb director systems	1	--	1
	30. Evaluate for correct operation, make authorized repairs and calibrations to:			
	a. Aircraft armament control test equipment	C	C	--
	b. Bomb director test equipment	C	--	C
	31. Evaluate repaired, overhauled, or newly installed aircraft armament control systems for proper and secure installation and optimum equipment performance	C	C	--
	32. Evaluate repaired, overhauled, or newly installed bomb director system for proper and secure installation and optimum equipment performance	C	--	C
	33. Analyze results of boresighting and alinement tests, computing and rate tests, and records of performance for alinement and computing accuracy within weapons systems	C	C	C
	34. Analyze electrical and electronic test data; reduce data and effect indicated corrections to aviation fire control equipment; compare values; set or determine values to be used for measuring responses	C	C	C
103	ADMINISTRATIVE AND/OR CLERICAL			
	1. Complete entries in equipment work logs, equipment histories, and performance records of:			
	a. Aircraft armament control systems	3	3	--
	b. Bomb director systems	3	--	3

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	**AQF**	**AQB**
103	ADMINISTRATIVE AND/OR CLERICAL—Continued			
	2. Prepare and complete entries in the following:			
	a. Aviation fire control equipment periodic check lists	3	3	3
	b. Stub requisition forms	3	3	3
	c. Failure and unsatisfactory reports (FUR)	3	3	3
	d. Standard Aircraft Inventory Logs	2	2	2
	3. Obtain part and stock numbers from available technical supply publications for obtaining replacement material; requisition, store, and account for materials and spare parts	2	2	2
	4. Evaluate completed equipment check lists, shop and equipment work logs, equipment histories, and equipment failure reports; review stub requisitions for spare parts, tools, and materials to be drawn from shop storeroom	1	1	1
	5. Prepare job orders and work requests	1	1	1
	6. Take, record, and report inventory of equipment, spare parts, tools, test equipment, and materials in shop and shop storeroom	1	1	1
	7. Prepare reports covering status and condition of aircraft armament control systems, associated test equipment, and shop work accomplished	C	C	--
	8. Prepare reports covering status and condition of bomb director systems, associated test equipment, and shop work accomplished	C	--	C
	9. Evaluate inventories in terms of shop requirements and prepare requisitions to replenish stock or to obtain new items for shop storeroom	C	C	C
200	EXAMINATION SUBJECTS			
201	OPERATIONAL			
	1. Safety precautions to be observed in working with or near electrical, electronic and ordnance equipment	3	3	3
	2. Effects of electrical shock, method of resuscitation of a person unconscious from electrical shock, treatment for electrical burns	3	3	3

Qualifications for advancement in rating	*Applicable rates* AQ	AQF	AQB
201 OPERATIONAL—Continued			
3. Purpose of the following operator's controls and adjustments:			
a. Intensity	3	3	3
b. Focus	3	3	3
c. Centering	3	3	3
d. Receiver gain	3	3	3
e. Receiver tuning	3	3	3
f. Dial lighting	3	3	3
g. Light filters	3	3	3
h. Azimuth and elevation controls	3	3	3
i. Range strobe control	3	3	--
j. Ranging throttle grip	3	3	--
4. Interpretation of dial settings into minutes, degrees, yards, or mils	3	3	3
5. Types and purposes of cathode ray tube presentations of radars used in aviation fire control	3	3	3
6. Effects of own aircraft motion and target motion in:			
a. Air-to-air and air-to-ground gunnery and rocketry	3	3	--
b. Horizontal, dive, toss and loft bombing	3	--	3
7. Effects of principal factors influencing trajectories of projectiles, including:			
a. Gravity	3	3	3
b. Air resistance	3	3	3
c. Wind	3	3	3
d. Angle of departure (initial angle of inclination) of projectile	3	3	3
e. Initial velocity	3	3	--
f. Rotation of projectile	3	3	--
g. Self-propelling force of rockets and missiles	3	3	--
8. Graphic resolution of vectors representing relative motion in and across line of sight	3	3	3

Qualifications for advancement in rating	*Applicable rates*		
	AQ	**AQF**	**AQB**
201 OPERATIONAL—Continued			
9. Types and functions of equipment used in aviation fire control, including:			
a. Armament control directors, and computers	3	3	3
b. Fire control radars	3	3	3
c. Noncomputing sights	3	3	--
d. Computing sights	3	3	--
e. Turret control equipment	3	3	--
f. Bomb directors	3	--	3
g. Armament control systems	3	3	--
10. Systems of assigning "AN" designations, marks and mods, and Aero designations to identify components of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
11. Graphic resolution of vectors representing relative motion and trajectory	2	2	2
12. Analytical solution of vectors representing relative motion and trajectory	1	1	1
13. Functional relationships among aircraft weapons; components of complete:			
a. Airborne intercept and turret systems, and other aircraft equipment supplying data to or receiving data from these systems	1	1	--
b. Bombing system and other aircraft equipment supplying data to or receiving data from these systems	1	--	1
14. Analysis of interior ballistics, exterior ballistics, and relative motion as applied to aviation fire control problems	C	C	--
15. Analysis of exterior ballistics and relative motion as applied to aviation bombing problems	C	--	C
16. Operating characteristics of:			
a. Airborne intercept and turret equipment	C	C	--
b. Airborne bombing equipment	C	--	C
17. Operating characteristics of aircraft weapons controlled by:			
a. Aircraft armament control systems	C	C	--
b. Bomb director systems	C	--	C

Qualifications for advancement in rating	rates Applicable		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR			
1. Types and purposes of hand tools and small portable power tools used in maintenance and repair of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
2. Methods of making electrical connections and splices, including soldering materials used	3	3	3
3. Function of and operating procedures in using the following:			
a. Voltmeter	3	3	3
b. Ammeter	3	3	3
c. Ohmmeter	3	3	3
d. Multimeter	3	3	3
e. Megger	3	3	3
f. Tube tester	3	3	3
g. Vacuum tube voltmeter	3	3	3
h. Oscilloscope	3	3	3
4. Operating principles of voltmeter, ammeter, and ohmmeter (but not vacuum tube voltmeter), including:			
a. D'Arsonval meter movement	3	3	3
b. Shunts and multipliers	3	3	3
c. Use of thermocouples and rectifiers in a-c meters	3	3	3
5. Meanings of mechanical, electrical, and electronic symbols used in schematic diagrams of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
6. Interpretation of schematic diagrams and wiring diagrams of electrical circuits	3	3	3
7. Units of electrical measurement, including:			
a. Ampere	3	3	3
b. Volt	3	3	3
c. Ohm	3	3	3
d. Watt	3	3	3
e. Volt-ampere	3	3	3
f. Cycle	3	3	3
g. Henry	3	3	3
h. Farad	3	3	3
i. Ampere-turn	3	3	3
j. Prefixing of mega, kilo, milli, and micro	3	3	3

Qualifications for advancement in rating	Applicable rates		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR—Continued			
8. Meaning of:			
a. Conductors and insulators	3	3	3
b. Phase	3	3	3
c. Frequency	3	3	3
d. Power factor	3	3	3
e. Self and mutual inductance	3	3	3
f. Reactance	3	3	3
g. Impedance	3	3	3
h. Lines of force	3	3	3
i. Field intensity	3	3	3
j. Flux density	3	3	3
k. Permeability	3	3	3
l. Hysteresis and eddy current	3	3	3
9. Function of the following in electrical circuits:			
a. Resistors	3	3	3
b. Rheostats and potentiometers	3	3	3
c. Solenoids	3	3	3
d. Inductors	3	3	3
e. Capacitors	3	3	3
f. Fuses	3	3	3
g. Switches	3	3	3
h. Reactors	3	3	3
i. Transformers	3	3	3
j. Relays	3	3	3
10. Component parts of motors, generators, and alternators; application of laws of magnetism to electrical rotating machinery	3	3	3
11. Relationship of resistance, temperature, and current in a conductor	3	3	3
12. Relationship of the length and cross-sectional area to the resistance of a conductor	3	3	3
13. Calculation of current, voltage, and resistance in d-c series and parallel circuits containing not more than four elements	3	3	3
14. Relationship of current, voltage, and impedance in a-c circuits	3	3	3
15. Relationship of resistance, inductance, and capacitance in a-c circuits	3	3	3

Qualifications for advancement in rating	*Applicable rates*		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR—Continued			
16. Lubricants and cleaning solutions used in maintenance of:			
a. Aircraft armament control system	3	3	--
b. Bomb director systems	3	--	3
17. Methods of cleaning commutators and slip ring assemblies and precautions to be followed	3	3	3
18. Types, construction, and operating principles of aircraft sights; procedures for boresighting aircraft sights	3	3	3
19. Standard color coding systems for resistors, capacitors, and wiring	3	3	3
20. Function of major components of radars, including transmitters, receivers, synchronizers, modulators, indicators, and antenna systems, used in:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
21. Function of and operating procedures in using the following:			
a. Signal generator	2	2	2
b. Frequency meter	2	2	2
c. Sweep generator	2	2	2
22. Operating principles of vacuum tube voltmeter	2	2	2
23. Effects of meter sensitivity in circuit voltage measurement	2	2	2
24. Interpretation of schematic diagrams and wiring diagrams of electronic circuits	2	2	2
25. Calculation of current, voltage, phase angle, frequency, impedance, and resonance in a-c series and parallel circuits containing not more than four elements	2	2	2
26. Relationship of reluctance, flux, and magnetomotive force in a-c and d-c magnetic circuits	2	2	2
27. Meaning of:			
a. Gain	2	2	2
b. Feedback	2	2	2
c. Bias, cut-off, and grid current	2	2	2
d. Electron tube characteristic curves	2	2	2
e. Electron tube constants	2	2	2
f. Class A, AB, B, and C operation	2	2	2
g. Nonlinear, frequency, and phase distortion	2	2	2

Qualifications for advancement in rating	*Applicable rates*		
	AQ	**AQF**	**AQB**
MAINTENANCE AND/OR REPAIR—Continued			
28. **Function** of electron tubes, including:			
a. **Application** of electron tubes to rectification, amplification, oscillation, and wave shaping	2	2	2
b. **Function** of elements in diodes, triodes, tetrodes, and pentodes	2	2	2
c. Types and functions of gas-filled tubes and cathode ray tubes	2	2	2
29. Methods of coupling:			
a. Resistance (R–C networks)	2	2	2
b. Impedance (R–C–L) networks)	2	2	2
c. Transformer	2	2	2
d. Direct	2	2	2
30. Operating principles of:			
a. Rectifiers: Half-wave, full-wave, bridge	2	2	2
b. Filter circuits	2	2	2
c. Regulators	2	2	2
d. Amplifiers: Voltage, power	2	2	2
e. Diode detectors	2	2	2
f. Amplitude modulators	2	2	2
g. Limiters	2	2	2
h. Cathode followers	2	2	2
i. Differentiators	2	2	2
j. Integrators	2	2	2
31. Functions of gyroscopes used in:			
a. Aircraft armament control systems	2	2	--
b. Bomb director systems	2	--	2
32. Function and operating principles of electro-hydraulic servomechanisms	2	2	2
33. Characteristics and use of synchros and servo motors; methods of setting to electrical zero; purpose of gain, phase, and balancing adjustments	2	2	2
34. Function and application of basic fire control mechanisms in solving the aviation fire control problem	2	2	2
35. Function of electronic and mechanical analogue circuits in aircraft computers	2	2	2
36. Operating principles of oscilloscope	2	2	2

Qualifications for advancement in rating	*rates Applicable*		
	AQ	**AQF**	**AQB**
202 MAINTENANCE AND/OR REPAIR—Continued			
37. Operating principles of:			
a. Cathode-ray tubes	2	2	2
b. Tuned coupling circuits	1	1	1
c. RF amplifiers	1	1	1
d. IF amplifiers	1	1	1
e. Video amplifiers	1	1	1
f. Oscillators: Tuned-grid, Hartley, Colpitts, TPTG, crystal-controlled, electron-coupled	1	1	1
g. Clippers	1	1	1
h. AGC circuits	1	1	1
i. AFC circuits	1	1	1
j. Blocking oscillators	1	1	1
k. Trigger circuits and multivibrators	1	1	1
l. Sawtooth generators	1	1	1
m. Peakers	1	1	1
n. Clampers	1	1	1
38. Function of and operating procedures in using the following:			
a. Range calibrator	1	1	1
b. Spectrum analyzer	1	1	1
c. RF wattmeter	1	1	1
d. Wavemeter	1	1	1
e. Echo box	1	1	1
39. Application of oscilloscopic wave form analysis to location of circuit malfunctions	1	1	1
40. Loading effects of test equipment on critical circuits, such as oscillators, tanks and wave shaping	1	1	1
41. Purpose and methods of making:			
a. Microwave power measurements	1	1	1
b. Sensitivity tests	1	1	1
c. Measurements of frequency spectrum of pulsed signals	1	1	1
d. Calibration measurements of range circuits	1	1	1

Qualifications for advancement in rating	*Applicable rates*		
	AQ	**AQF**	**AQB**
202 **MAINTENANCE AND/OR REPAIR—Continued**			
42. Types and functions of:			
a. Wave-guide sections	1	1	1
b. Coaxial cables	1	1	1
c. T/R and AT/R tubes	1	1	1
d. Klystrons	1	1	1
e. Magnetrons	1	1	1
f. Crystal mixers	1	1	1
43. Operating principles and characteristics of rate and stabilizing gyros	1	1	1
44. Characteristics and construction of boresighting fixtures and target boards	1	1	1
45. Circuitry and characteristics of standard electronic test equipment	C	C	C
46. Relation of tube characteristics and tube constants to electronic circuitry	C	C	C
47. Operating principles of:			
a. Magnetic amplifiers	C	C	C
b. Wave guides and coaxial cables	C	C	C
c. T/R and AT/R tubes	C	C	C
d. Klystrons	C	C	C
e. Magnetrons	C	C	C
f. Crystal mixers	C	C	C
48. Radiation characteristics of parabolic and lens antennas	C	C	C
203 **ADMINISTRATIVE AND/OR CLERICAL**			
1. Types of forms and records used in maintenance and repair of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
2. Types of entries and information recorded in the following:			
a. Aviation fire control equipment periodic check lists	3	3	3
b. Stub requisitions forms	3	3	3
c. Failure and unsatisfactory reports (FUR)	3	3	3
d. Standard Aircraft Inventory Logs	2	2	2

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	**AQF**	**AQB**
203	ADMINISTRATIVE AND/OR CLERICAL—Continued			
	3. Types of information pertinent to aviation fire control equipment contained in publications and instructions furnished by technical bureaus and manufacturers, including:			
	a. Aircraft Service Changes; handbooks of service instructions, handbooks of operation instructions; Ordnance Publications; Ordnance Data; Ordnance Circular Letters and Ordnance Alterations	3	3	3
	b. Allowance Lists; parts catalogs; Aviation Circular Letters; Electronic Material Bulletins and Changes	2	2	2
	4. Procedure for obtaining replacement parts, tools, test equipment, and materials for use within the shop	1	1	1
	5. Procedures for accounting for aviation fire control equipment, maintaining control of inventories and work flow, reporting equipment status and work accomplished	C	C	C
300	PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER			
	Aviation Fire Control Technicians advance to Warrant Aviation Ordnance Technician and/or to Limited Duty Officer, Aviation Ordnance. As an alternate, Aviation Fire Control Technicians advance to Warrant Aviation Electronics Technician and/or to Limited Duty Officer, Aviation Electronics.			

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